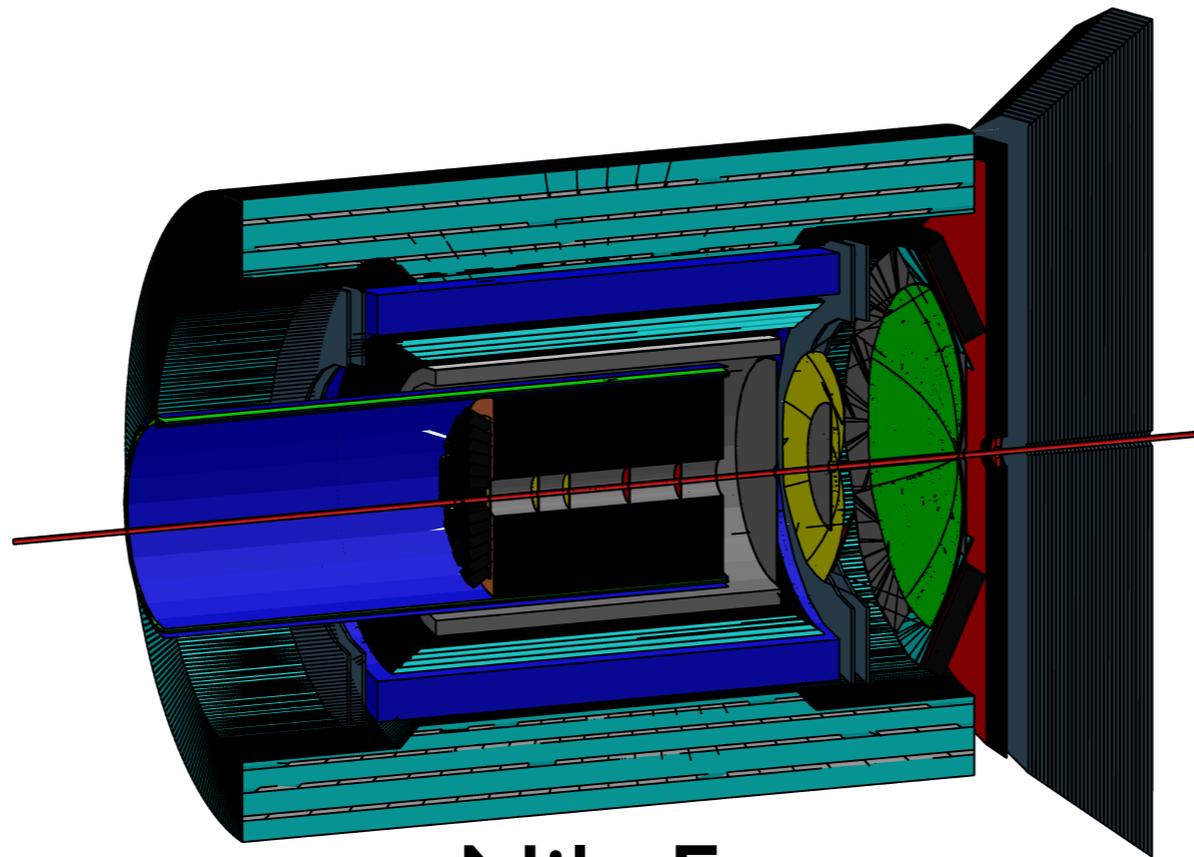


Stony Brook University

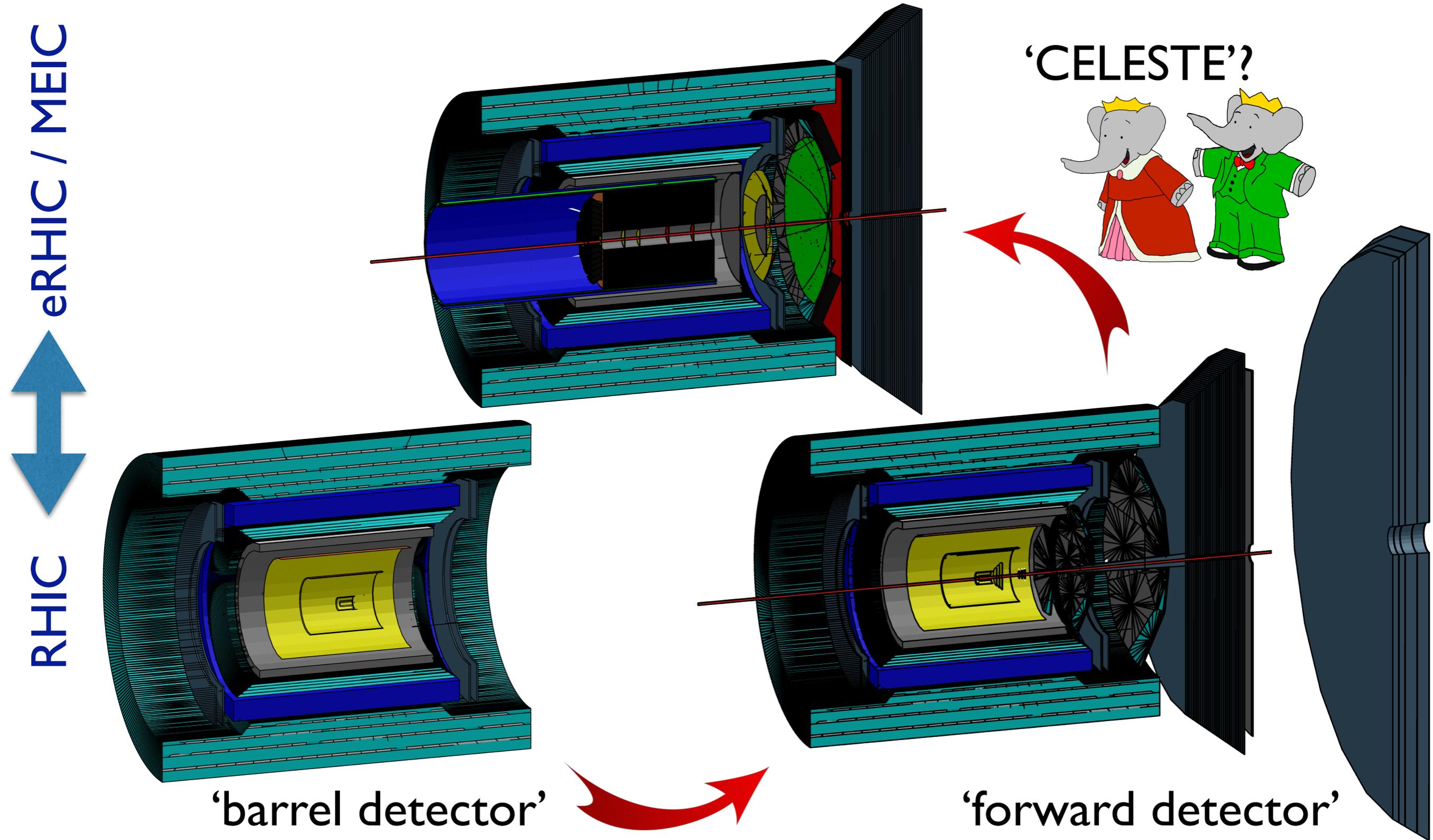
A Path Into the Future: Detectors for Forward Physics and EIC



Nils Feege

Simulation Workfest for A Large-Acceptance Jet and Upsilon Detector for RHIC
Stony Brook University, July 27 - July 31 2015

Evolution towards an EIC Detector

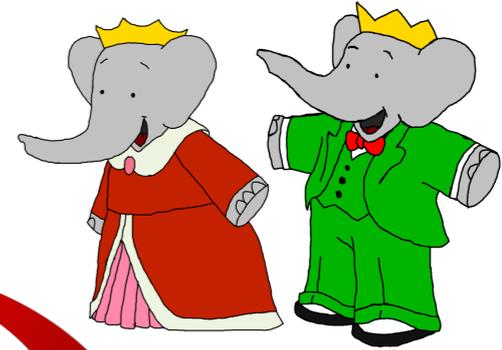


Putting The Pieces Together

eRHIC / MEIC
↕
RHIC

- Nucleon spin and 3D structure
- Effects of 'cold' nuclear matter
- Color Glass Condensate

'CELESTE'?



- Quark-gluon plasma
- Effects of 'hot' nuclear matter

- Transverse spin
- Effects of 'cold' nuclear matter

'barrel detector'

'forward detector'

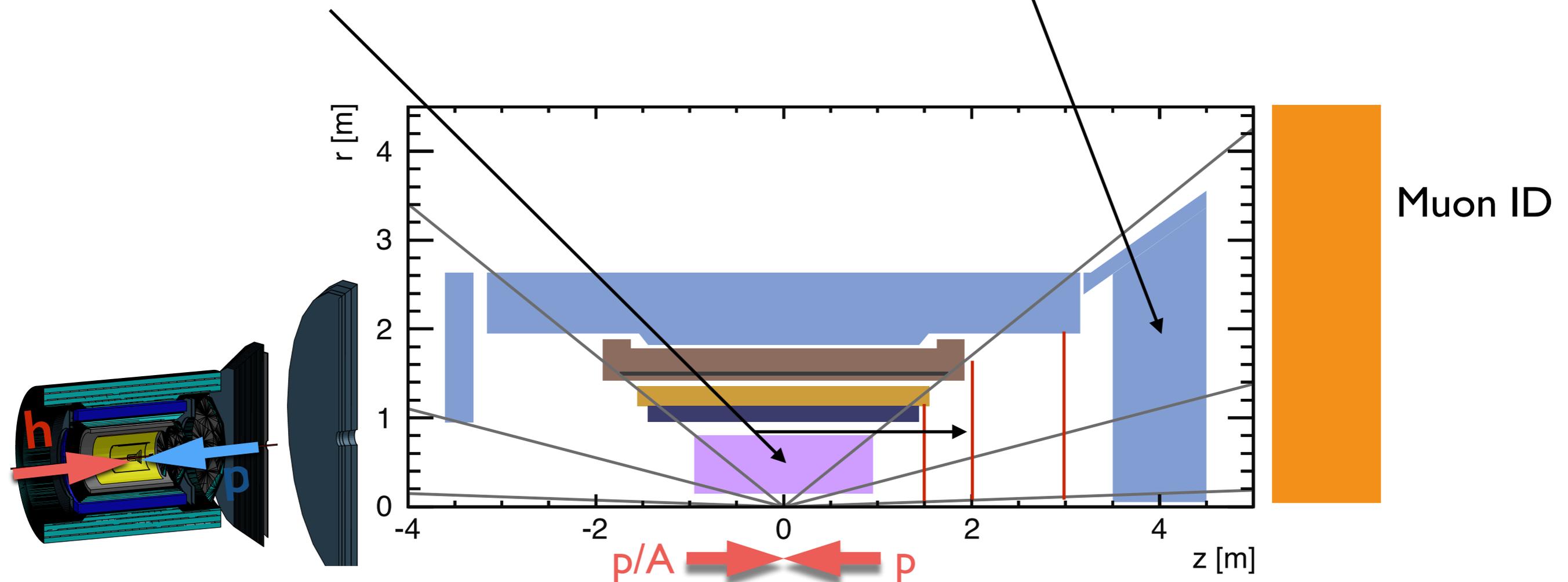
Forward Detectors in pp / pA

Tracking

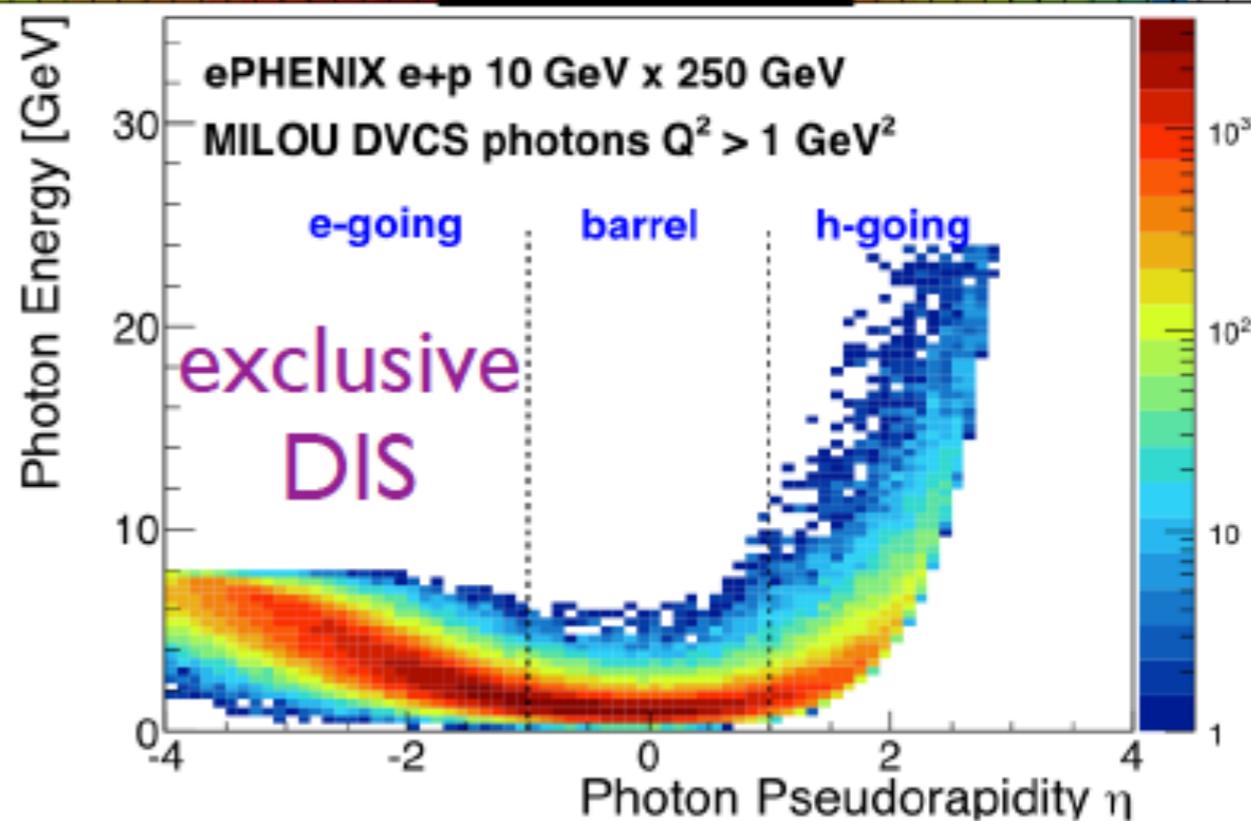
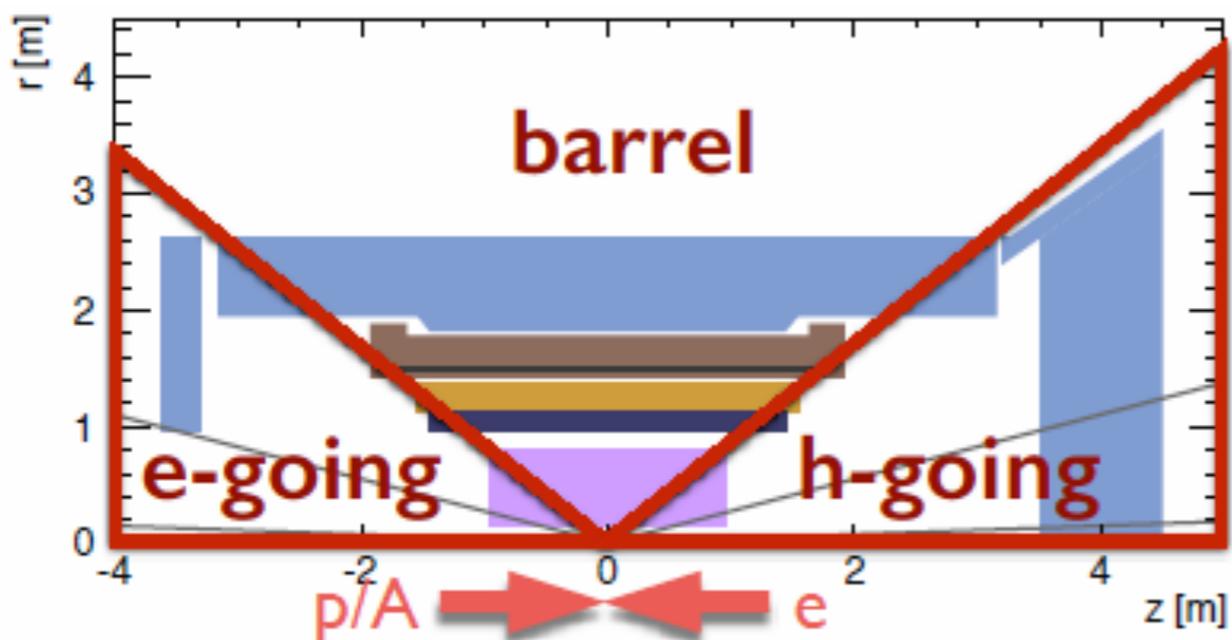
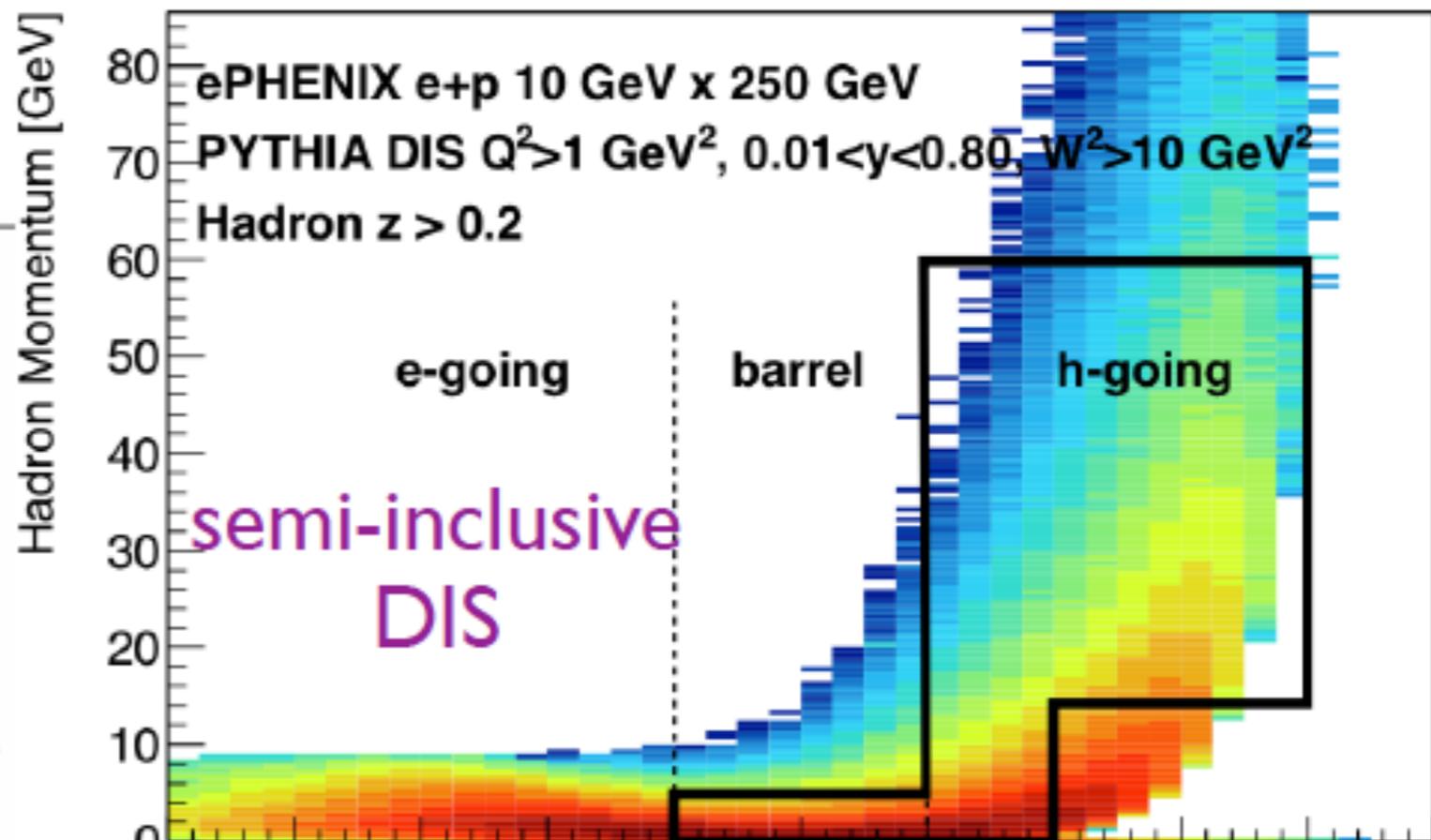
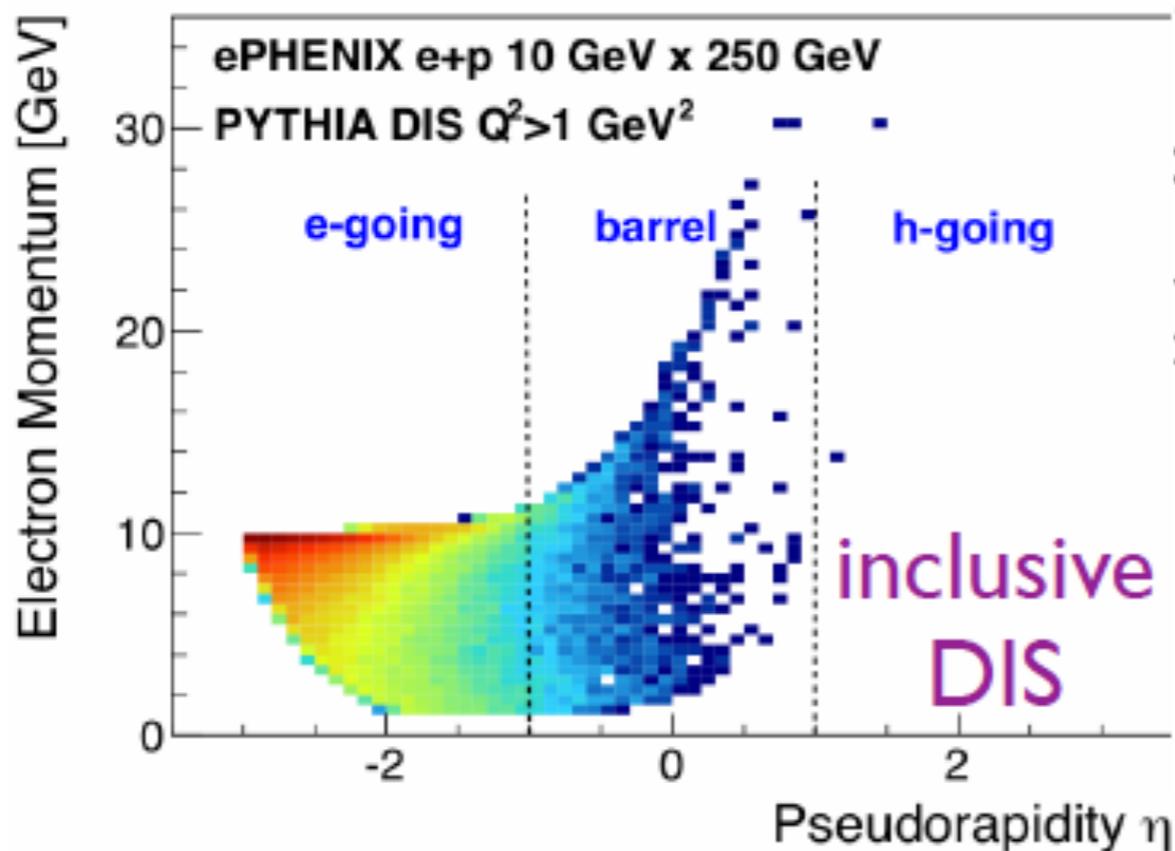
- 2 layer Silicon vertex pixel
- Silicon-strip OR TPC
- FVTX
- GEM ($r\delta\varphi$ resolution $\sim 100\mu\text{m}$)

Hadron Calorimeter

- Steel-scintillator ($5 \lambda_{\text{int}}$)
- $100\%/\sqrt{E}$ energy resolution
- $\sim 10 \times 10 \text{ cm}^2$ segmentation



Measuring DIS



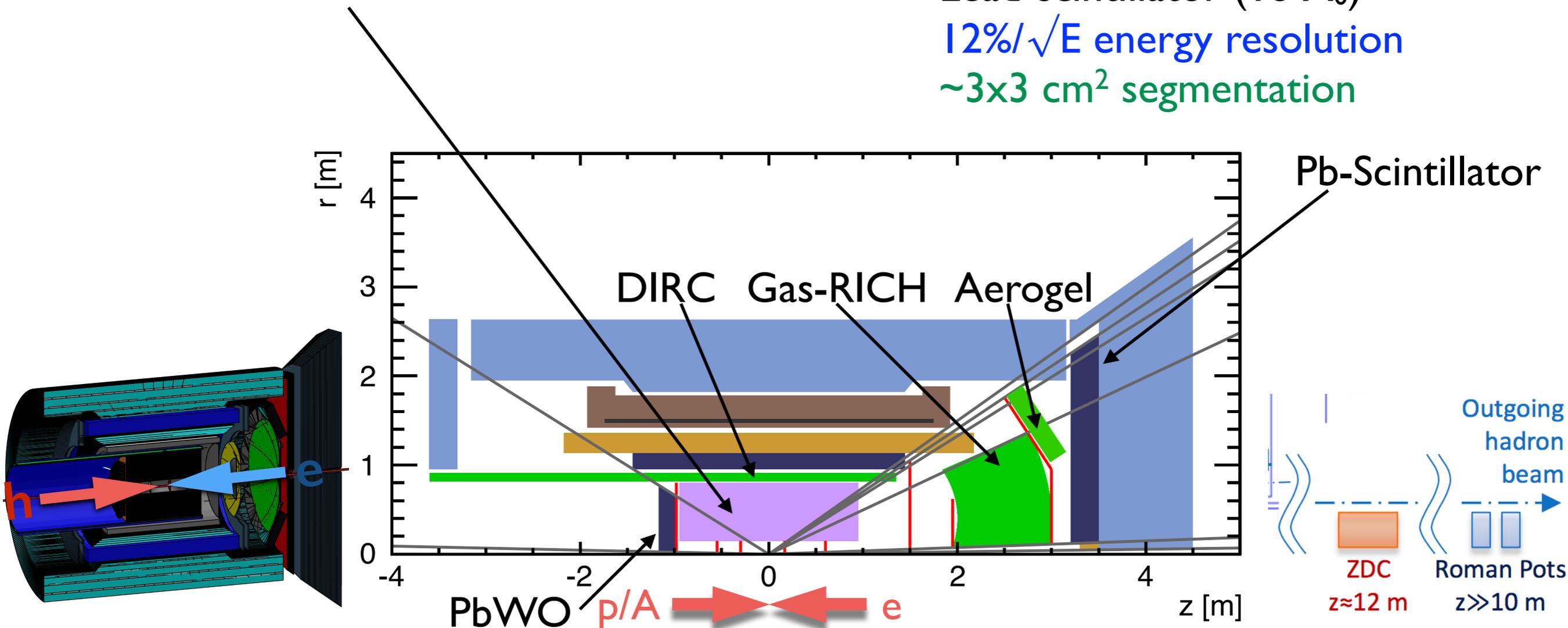
The detector in the EIC era

Tracking

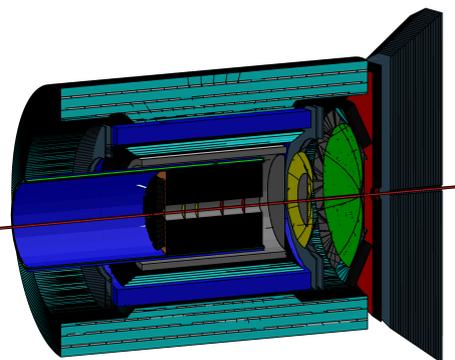
- TPC (300 μm position resolution)
- GEMs (50-100 μm resolution in $r\Delta\varphi$)

Electromagnetic Calorimeter

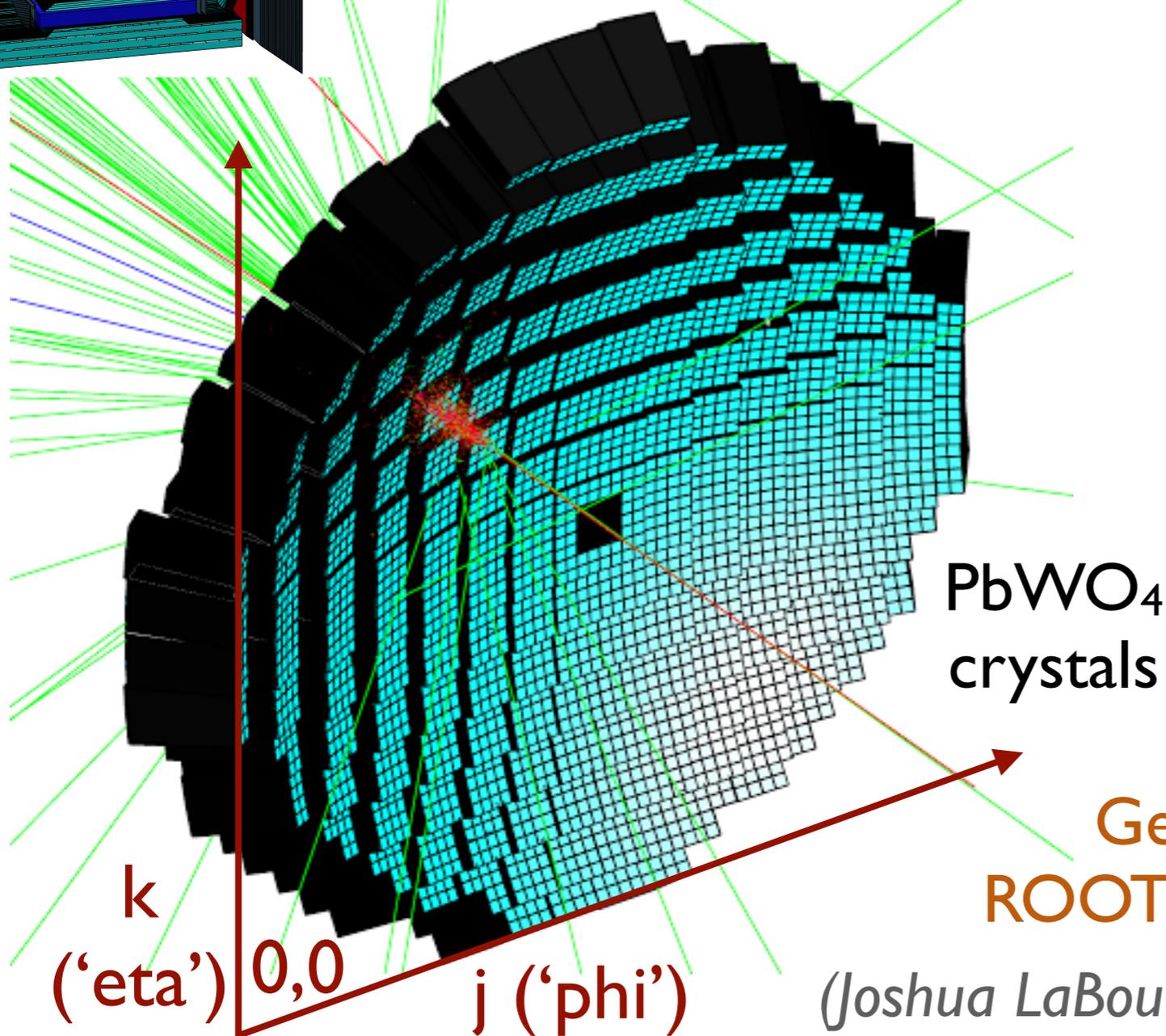
- Lead-tungstate ($20 X_0$)
1.5%/ \sqrt{E} energy resolution
3mm/ \sqrt{E} position resolution
- Lead-scintillator ($18 X_0$)
12%/ \sqrt{E} energy resolution
 $\sim 3 \times 3 \text{ cm}^2$ segmentation



Detailed Crystal Calorimeter Implementation in Geant4



Carbon fiber frame



PbWO₄ crystals

k
(‘eta’) 0,0

j (‘phi’)

Geometry class?
ROOT::TGeometry?

(Joshua LaBounty, SBU)

PHG4CrytalCalorimeterSubsystem

stores *j*, *k*
of crystal

G4Hitv8

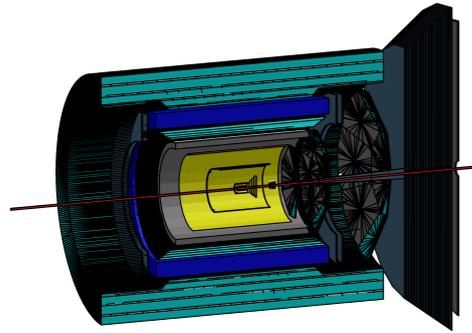
CrystalCalorimeterTowerBuilder

RawTowerv1

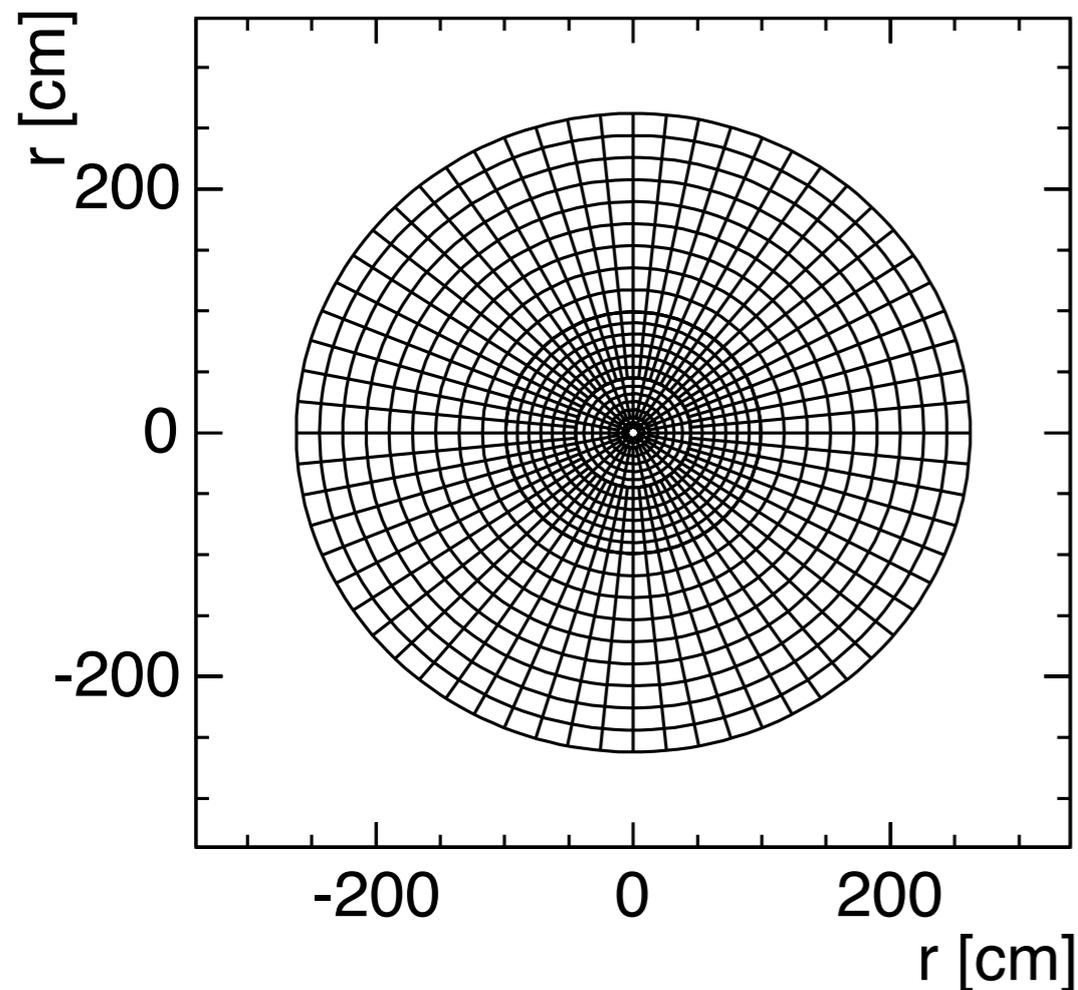
CrystalCalorimeterDigitization

RawTowerv1

Forward sampling calorimeter segmentation



HCAL tower barrel: 0.1×0.1 (eta, phi) $\sim 20 \times 20$ cm²



# r	# phi	dr [cm]	dphi [cm]
2	16	4	2 - 5
5	32	6	3 - 9
6	64	9	4 - 10
9	64	18	10 - 26

Forward HCAL total: 1152 towers

G4Hit

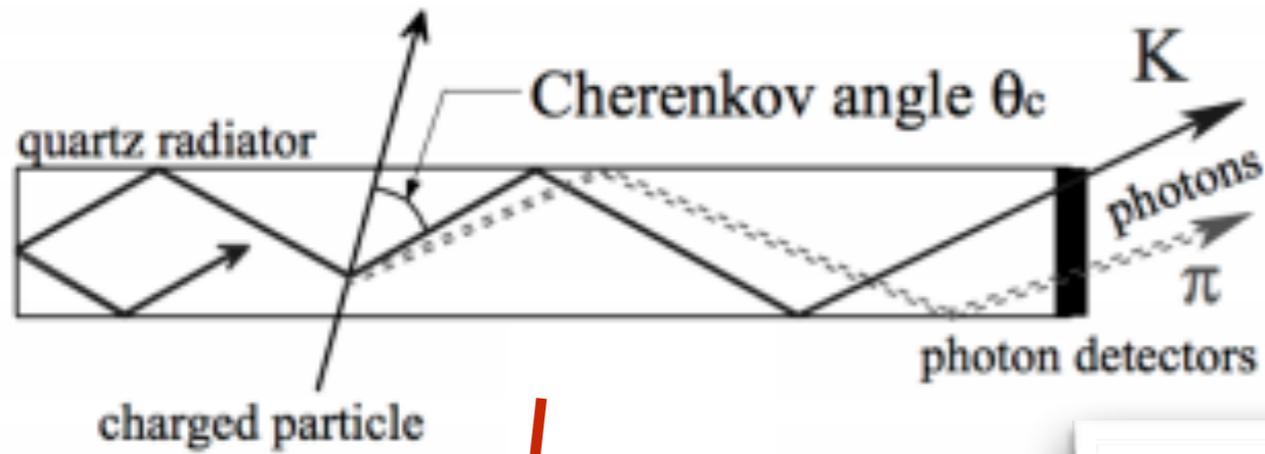


RawTowerBuilderCone

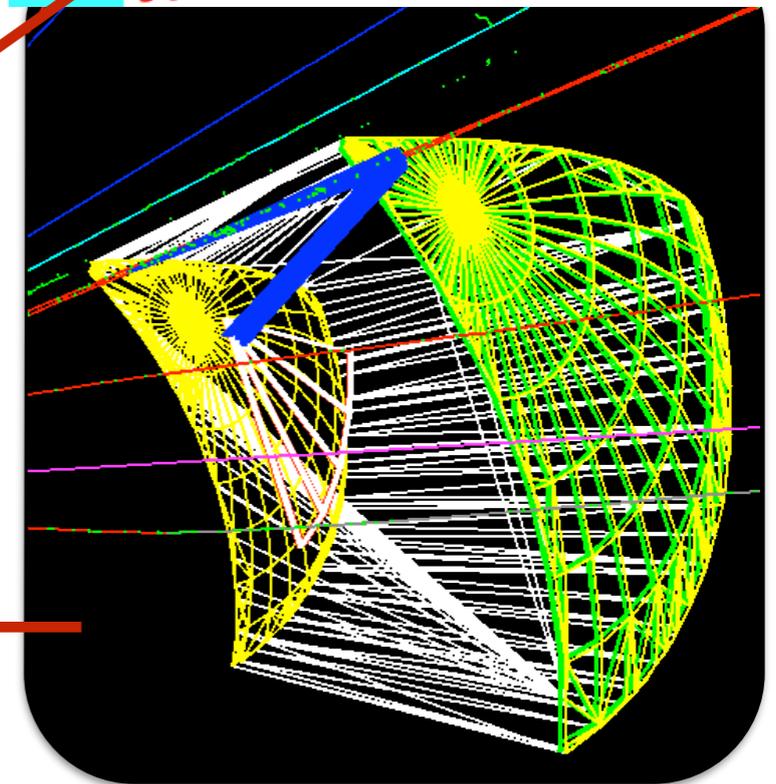
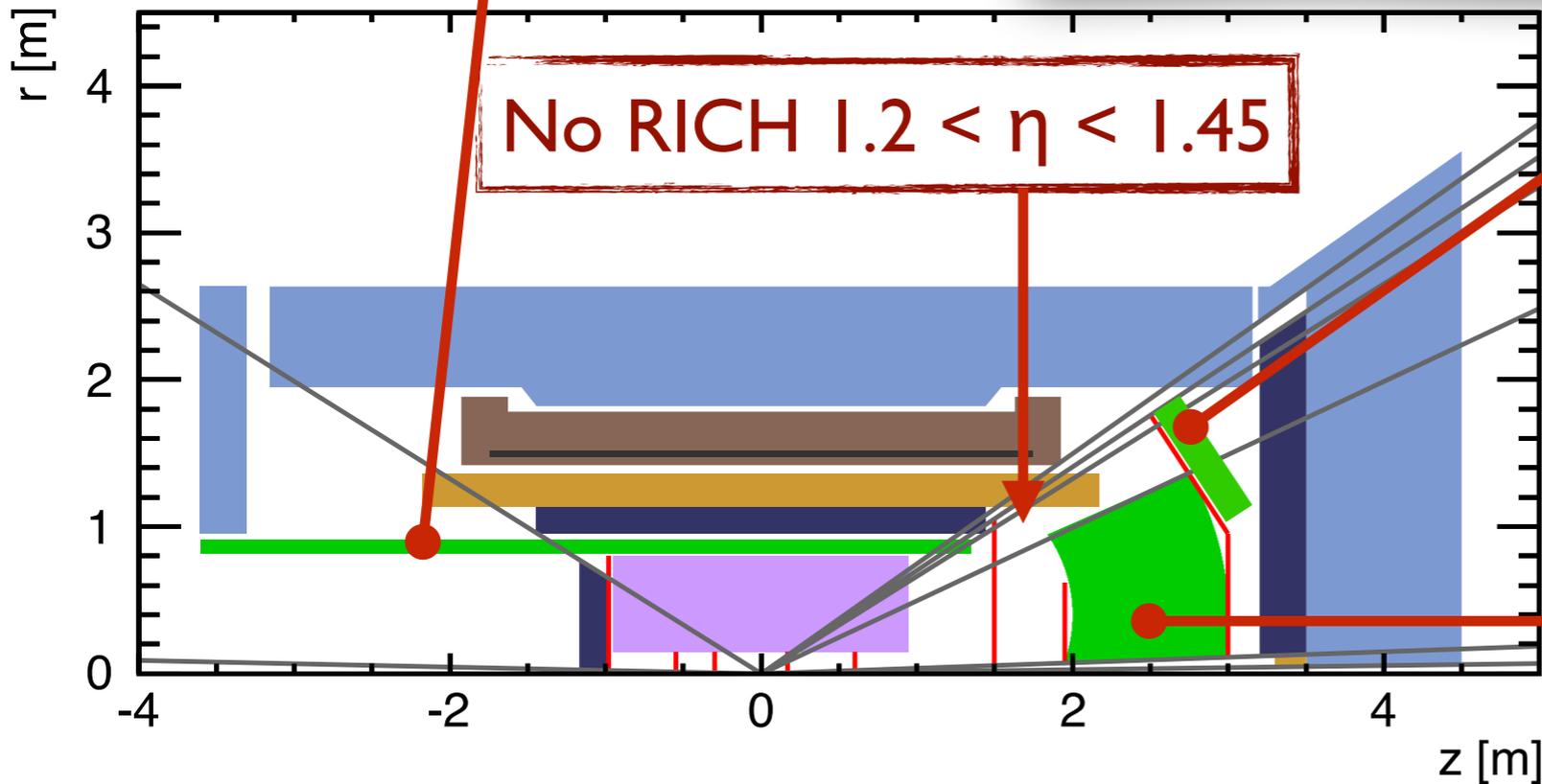
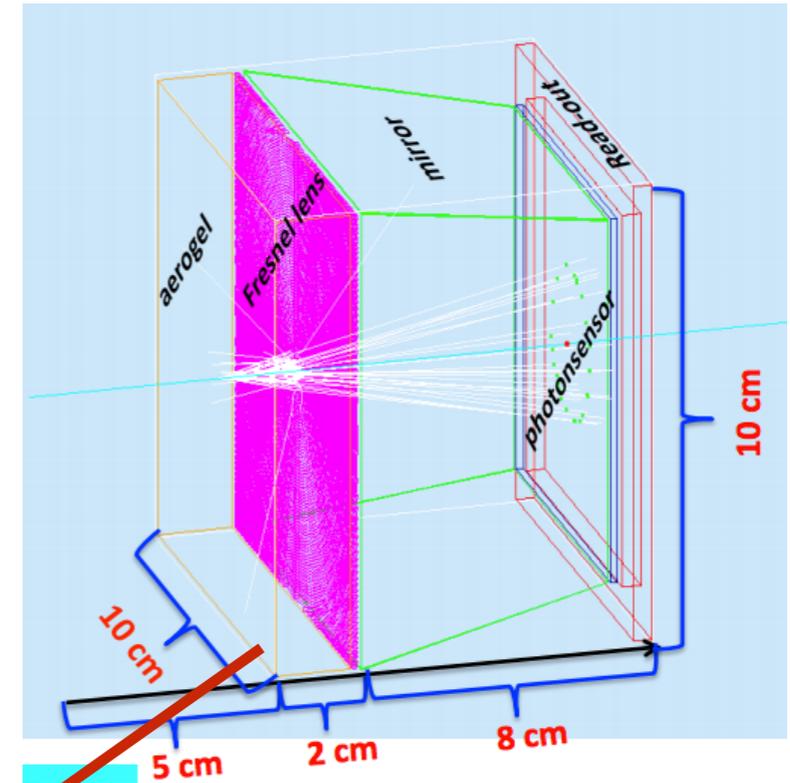


RawTowerv1

RICH Detectors for EIC Hadron ID



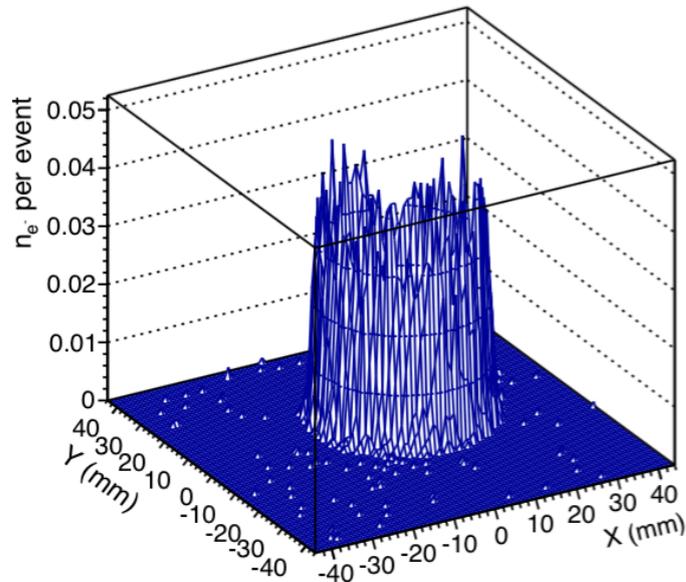
$$\theta_c = \cos^{-1} \left(\frac{1}{\beta n} \right)$$



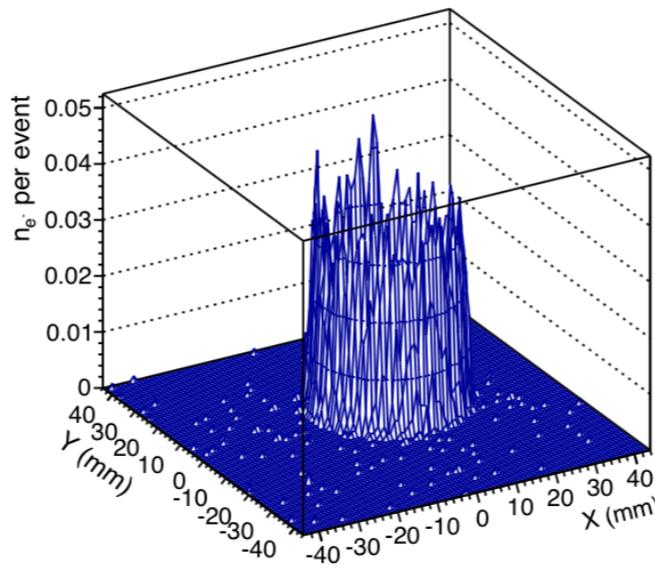
Likelihood Analysis for PID

Detector Responses:

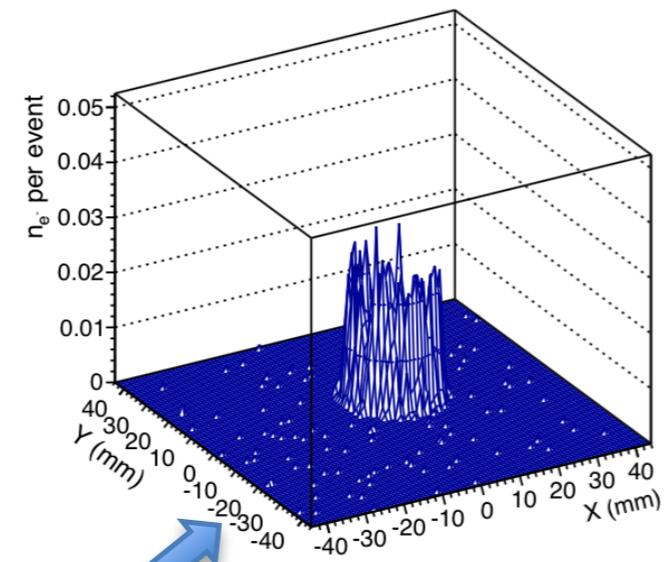
5 GeV Pion, shoot angle: $\theta=5^\circ$, $\phi=45^\circ$



5 GeV Kaon, shoot angle: $\theta=5^\circ$, $\phi=45^\circ$



5 GeV Proton, shoot angle: $\theta=5^\circ$, $\phi=45^\circ$

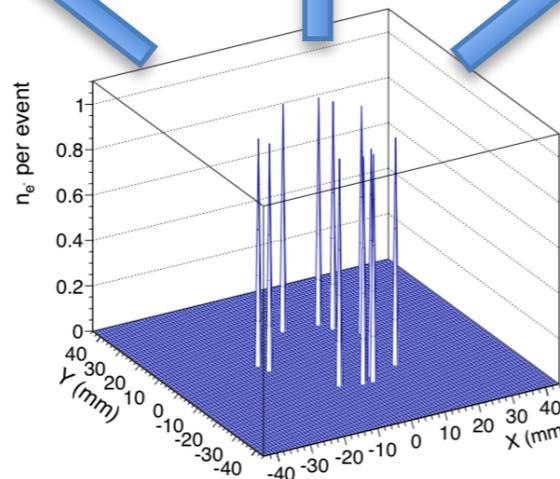


Particle Identification: Bin by Bin

unknown particle:



5 GeV Pion, shoot angle: $\theta=5^\circ$, $\phi=45^\circ$



Prob(π) , Prob(K) , Prob(p)



(Liang Xue, GSU; developed for modular gas rich in MEIC)

Forward / EIC Detector Tasks

- ◆ Calorimeter: Energy leakage (Joshua LaBounty)
- ◆ Calorimeter: Mapping / geometry class
- ◆ Calorimeter: Clustering, track matching
- ◆ Forward ECAL / HCAL: Tower geometry implementation
- ◆ Tracking: Inhomogeneous fields, Kalman Filter
- ◆ PID detector implementations (Gas RICH, Aerogel, DIRC)
(Robert Bruce, Kaustuv Datta for Gas RICH, Alan Dion + student had first look at DIRC with PandaROOT)
- ◆ PID detector: Adapt likelihood analysis for our detectors
- ◆ Modules to evaluate subsystem performances

A full detector simulation will allow us to evaluate:

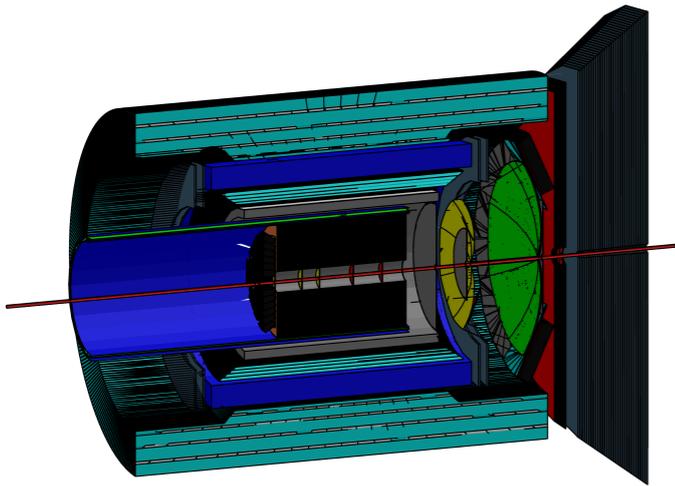
p+p

- Drell-Yan backgrounds and event rejection using full event characterization
- Full reconstruction of W decays catching the recoil jet

e+p

- Electron / hadron / photon separation
- Hadron identification (pion / kaon / proton)
- Migration of events in kinematic bins, detector unfolding
- Explore physics analysis potential

Forward and EIC Detector Software on GitHub

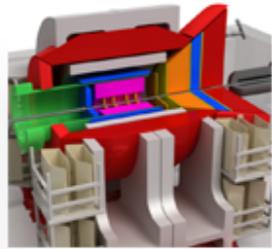


<https://github.com/EIC-Detector>

- ❖ **coresoftware-eic**
Additional Fun4All libraries and macros for full EIC detector simulations
- ❖ **analysis-calorimeter, analysis-pythia, ...**
Analysis-specific code, macros, and more.

Check out: **Public**
Commit: **Restricted**

EIC Detector Simulation Wiki



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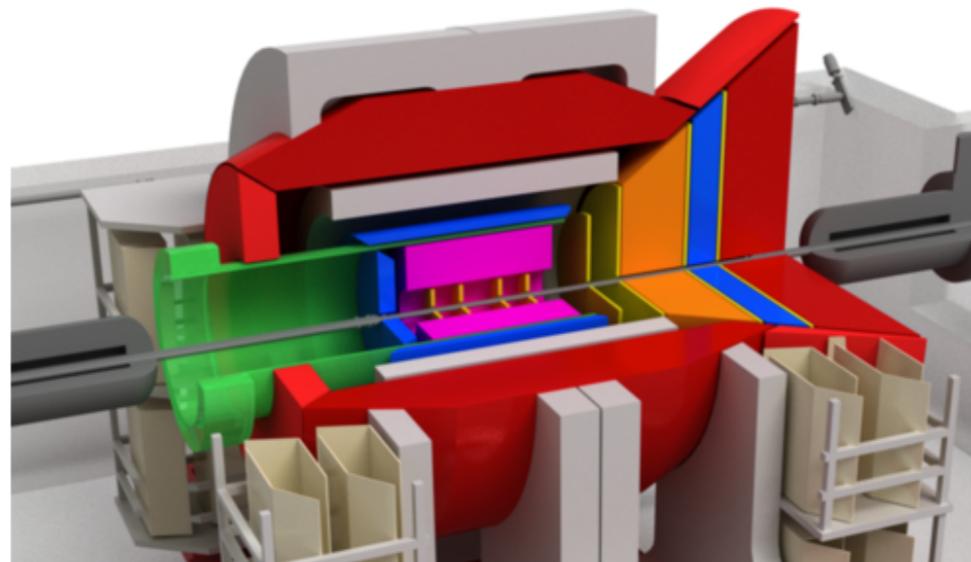
[Read](#)

An EIC Detector Built Around The BaBar Solenoid

Contents [\[hide\]](#)

- [1 Introduction to an EIC Detector Built Around the BaBar Solenoid](#)
- [2 Detector Systems](#)
- [3 Event Generation](#)
- [4 Geant4 Simulation](#)
- [5 Analysis](#)
- [6 Other](#)
- [7 Getting started using the Wiki](#)

Introduction to an EIC Detector Built Around the BaBar Solenoid



View: **Public**

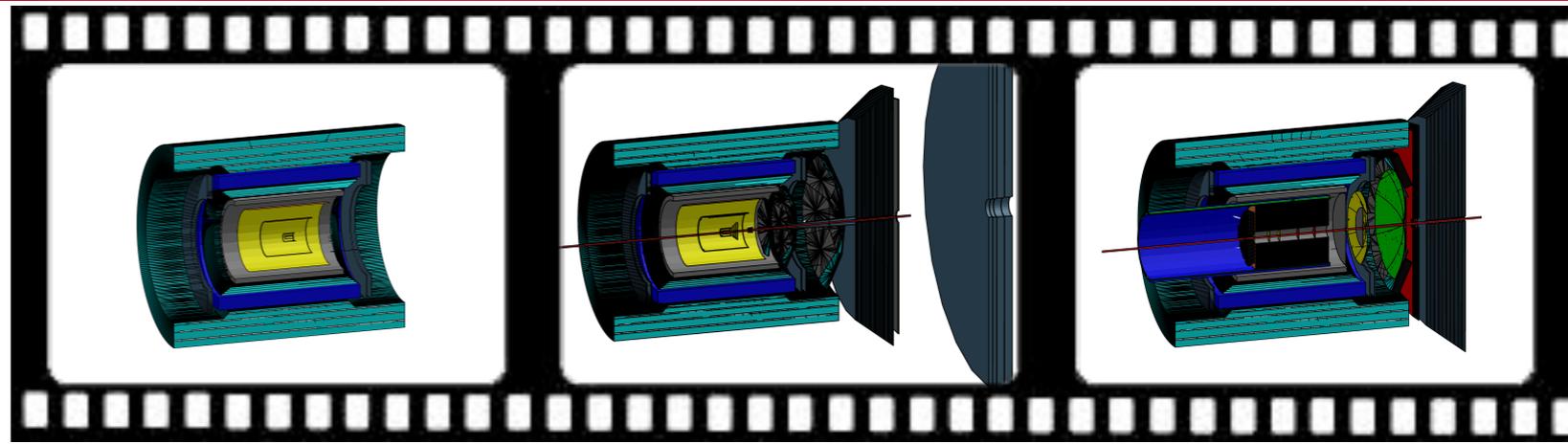
Edit: **Request account**

<http://zwarg.physics.sunysb.edu/mediawiki/eic/>

Our Current Simulation Efforts

- Meeting: <https://indico.bnl.gov/categoryDisplay.py?categId=93>
Joint EIC detector / fsPHENIX meeting (BlueJeans) every other Tuesday 9 pm EST; **Next: Tomorrow July 28, 2015**
- Mailing list: eic@stonybrook.edu
(eMail to nils.feege@stonybrook.edu to subscribe)
- PHENIX internal mailing lists: phenix-nextfor-1@lists.bnl.gov
phenix-ephenix-1@lists.bnl.gov
- Wiki: <http://zwarg.physics.sunysb.edu/mediawiki/eic/>
- GitHub: <https://github.com/EIC-Detector>

Summary



- ❖ Full detector simulation is necessary to quantify the performance of forward and EIC detector designs.
- ❖ Need compatibility between barrel and forward detector code-data format, mapping schemes, etc.
- ❖ Need to consider the whole evolution of the experiment at each design stage.
- ❖ Detector can naturally evolve to cover forward physics and into an EIC experiment that covers all critical acceptances and will do the essential Day I Physics.

ADDITIONAL SLIDES

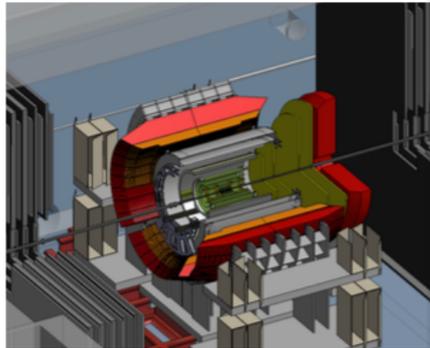


References

An Upgrade Proposal from the PHENIX Collaboration
Original: July 1, 2012
Updated: October 1, 2013
Updated: June 19, 2014
Updated: November 15, 2014

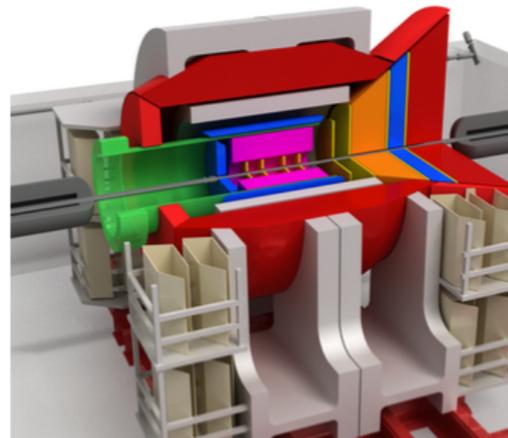


Future Opportunities in $p+p$ and $p+A$ Collisions at RHIC with the Forward sPHENIX Detector



The PHENIX Collaboration
April 29, 2014

Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid



arXiv:1402.1209v1 [nucl-ex] 5 Feb 2014

The PHENIX Collaboration
February 3, 2014



- ➔ sPHENIX - An Upgrade Proposal from the PHENIX Collaboration
- ➔ Future Opportunities in $p+p$ and $p+A$ Collisions at RHIC with the Forward sPHENIX Detector
- ➔ Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid [[arXiv:1402.1209v1](https://arxiv.org/abs/1402.1209v1)]
- ➔ Electron Ion Collider: The Next QCD Frontier [[arXiv:1212.1701v3](https://arxiv.org/abs/1212.1701v3)]
- ➔ eRHIC Design Study [[arXiv:1409.1633](https://arxiv.org/abs/1409.1633)]

$e+p$ / $e+A$ Collisions at RHIC

FFAG Recirculating Electron Rings

1.3-6.6 GeV

7.9-21.2 GeV

ERL Cryomodules

Beam Dump

Energy Recovery Linac,
1.32 GeV

Polarized
Electron Source

Coherent
Electron Cooler

Detector I

Detector II

hadrons

electrons

From AGS

Energy:

Electron: 6.6–21.2 GeV

Proton: 25–250 GeV

Ions: 10–100 GeV

\sqrt{s} : up to 145 GeV

Polarization:

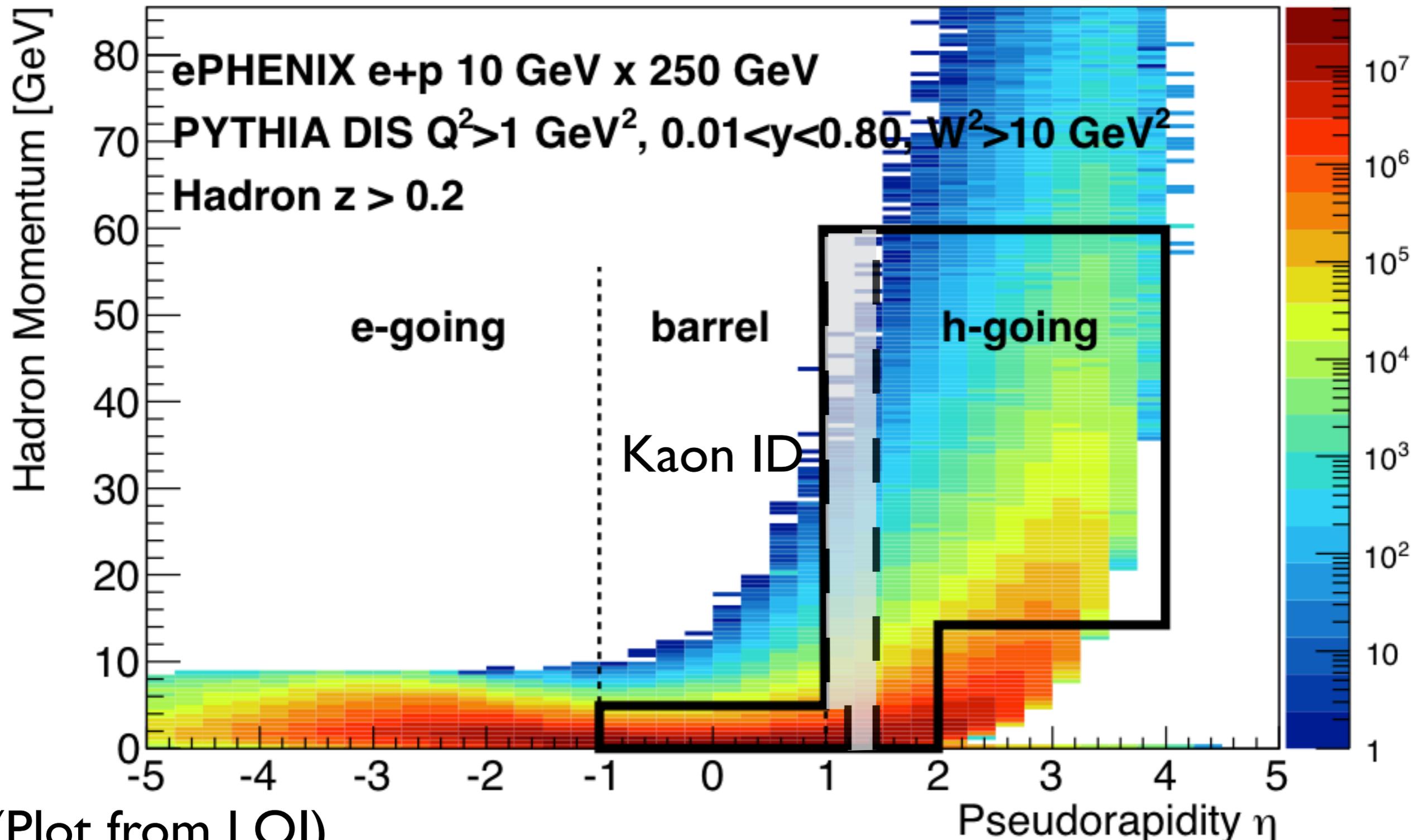
Electrons: 80%

Protons and He3: 70%

Luminosity:

$>10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Reduced PID Coverage



(Plot from LOI)

Setting The Stage for the LOI Studies

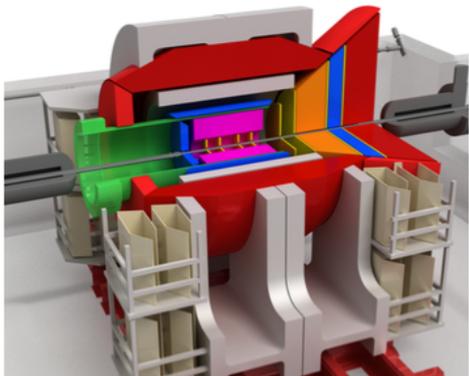
Maximum
beam energies

e	10 GeV
p	255 GeV
Au	100 GeV / nucleon

e+p Design luminosity
(10 GeV on 255 GeV)

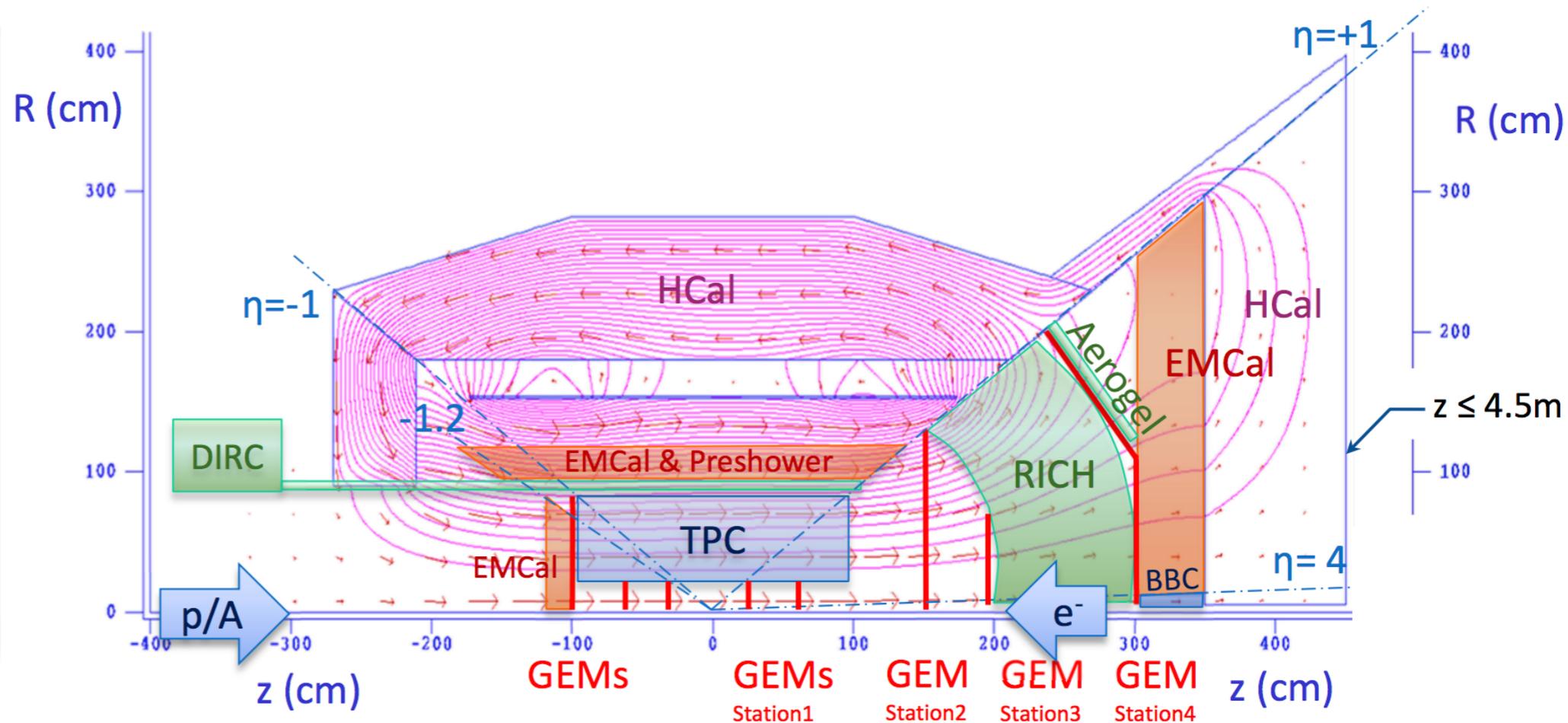
$10^{33} \text{ cm}^{-2}\text{s}^{-1}$

Concept for an Electron Ion Collider (EIC) detector built around the BaBar solenoid



The PHENIX Collaboration
February 3, 2014

[arXiv:1402.1209v1]

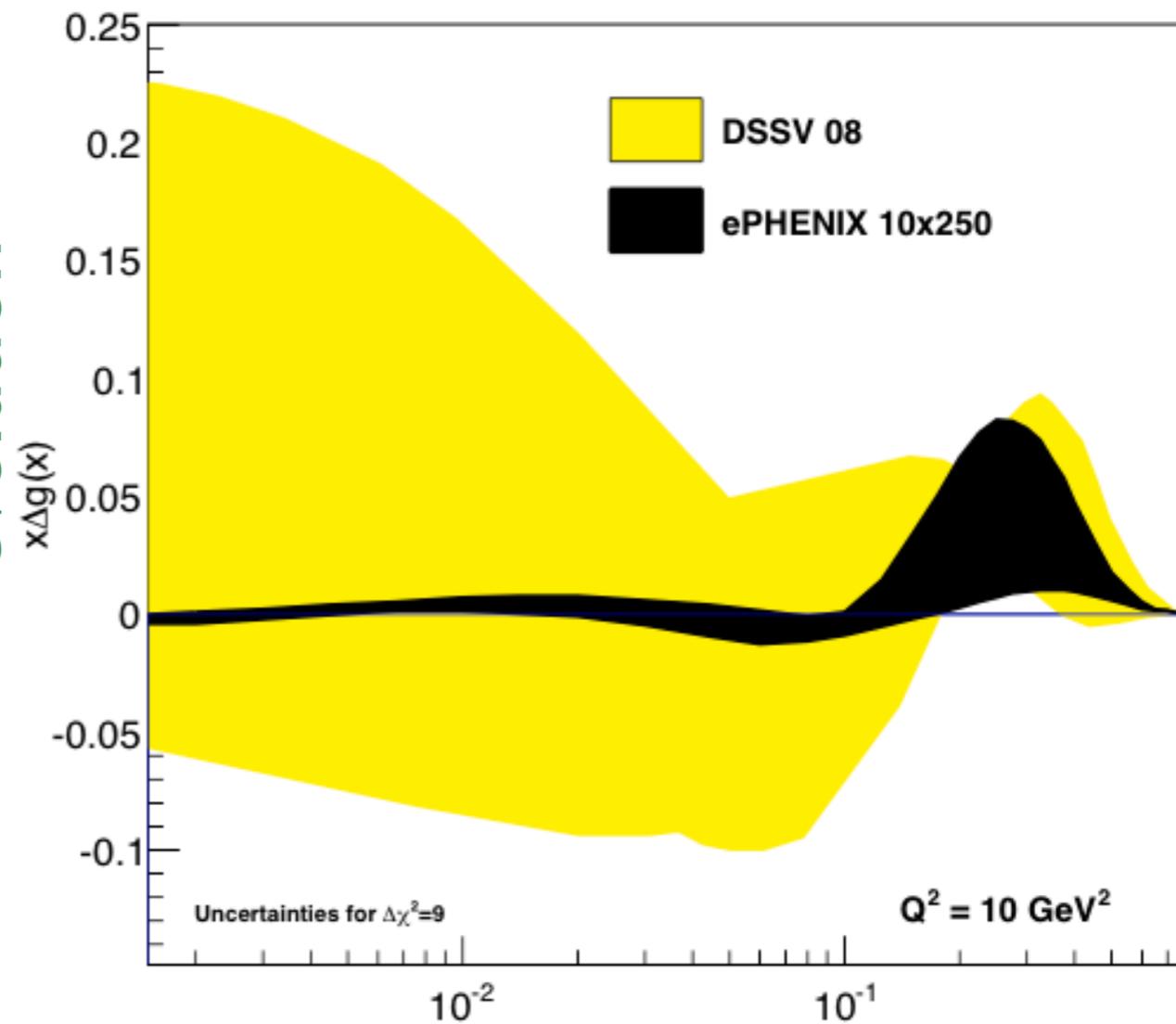
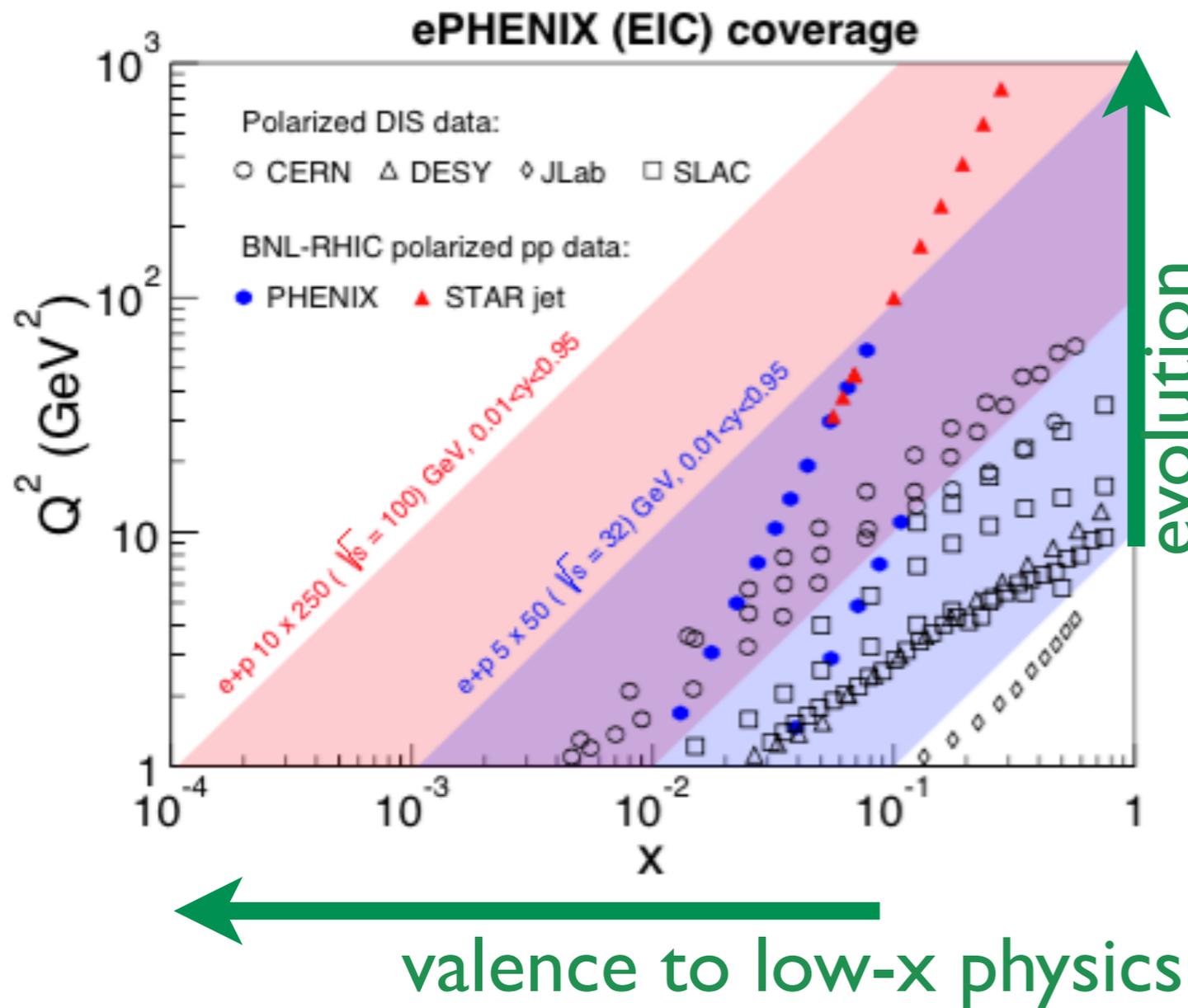


Proton Structure: Longitudinal Spin

$$\frac{1}{2} = \frac{1}{2} \Delta\Sigma + L_q + \Delta G + L_g$$

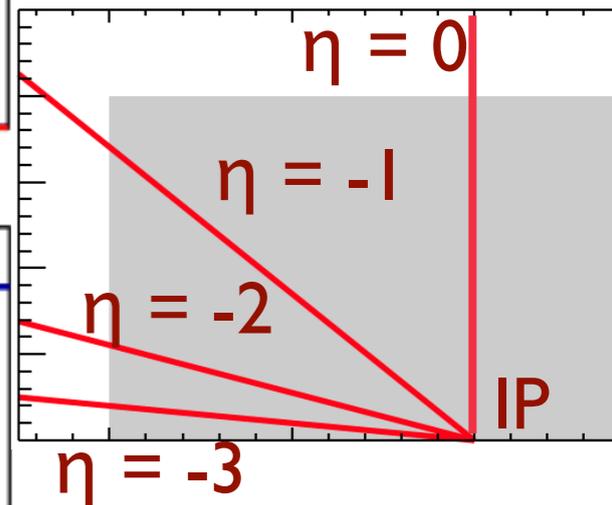
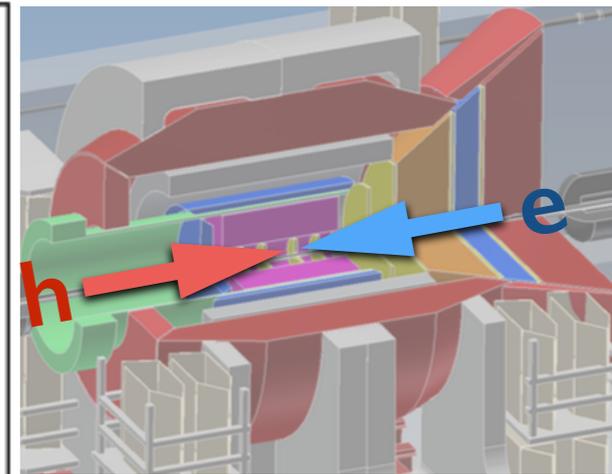
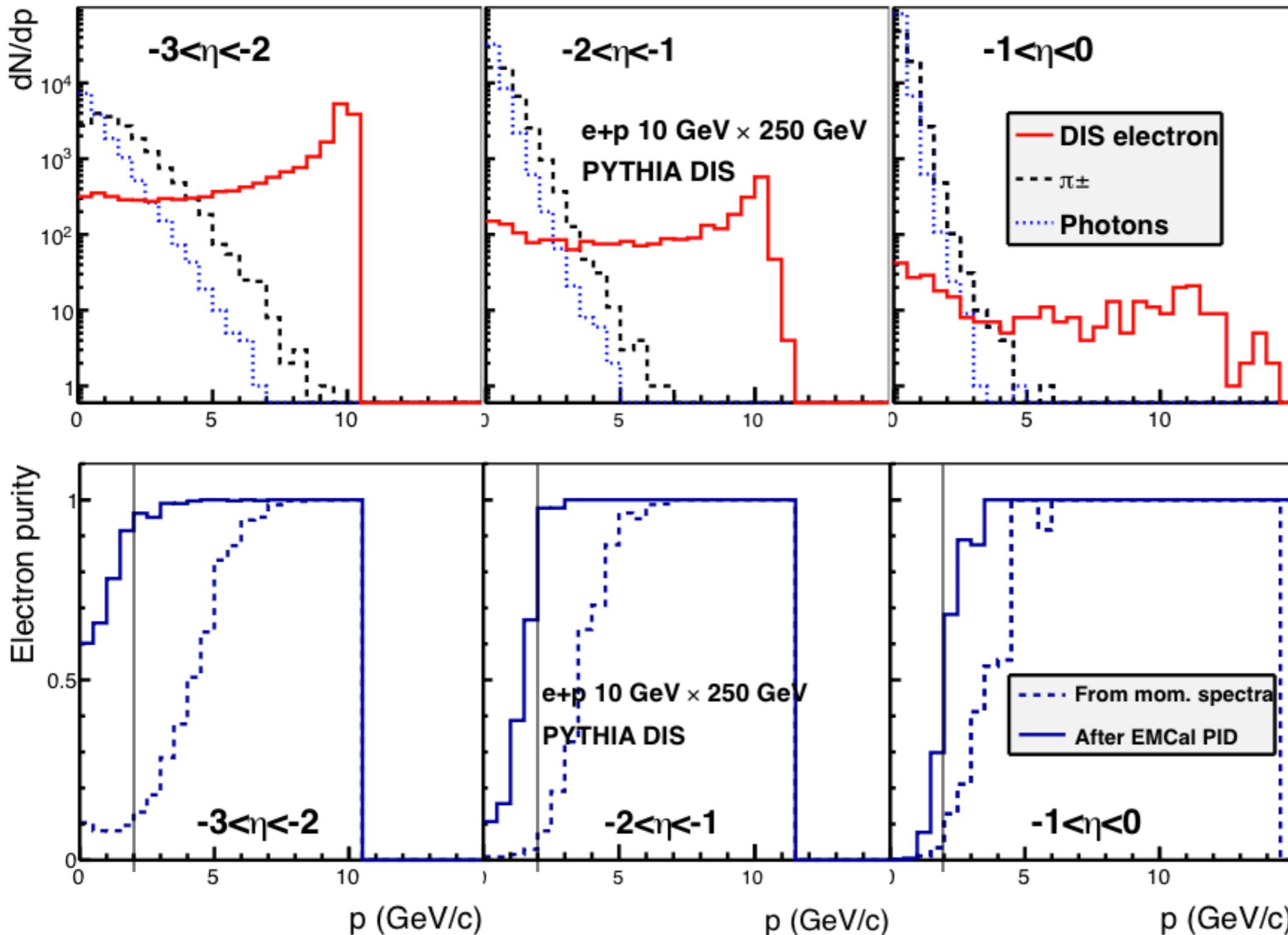
PHYTHIA generator and ePHENIX acceptance/efficiencies

10 fb⁻¹ at 10GeV×250GeV



arXiv:1402.1209v1

Electron ID via E/p matching



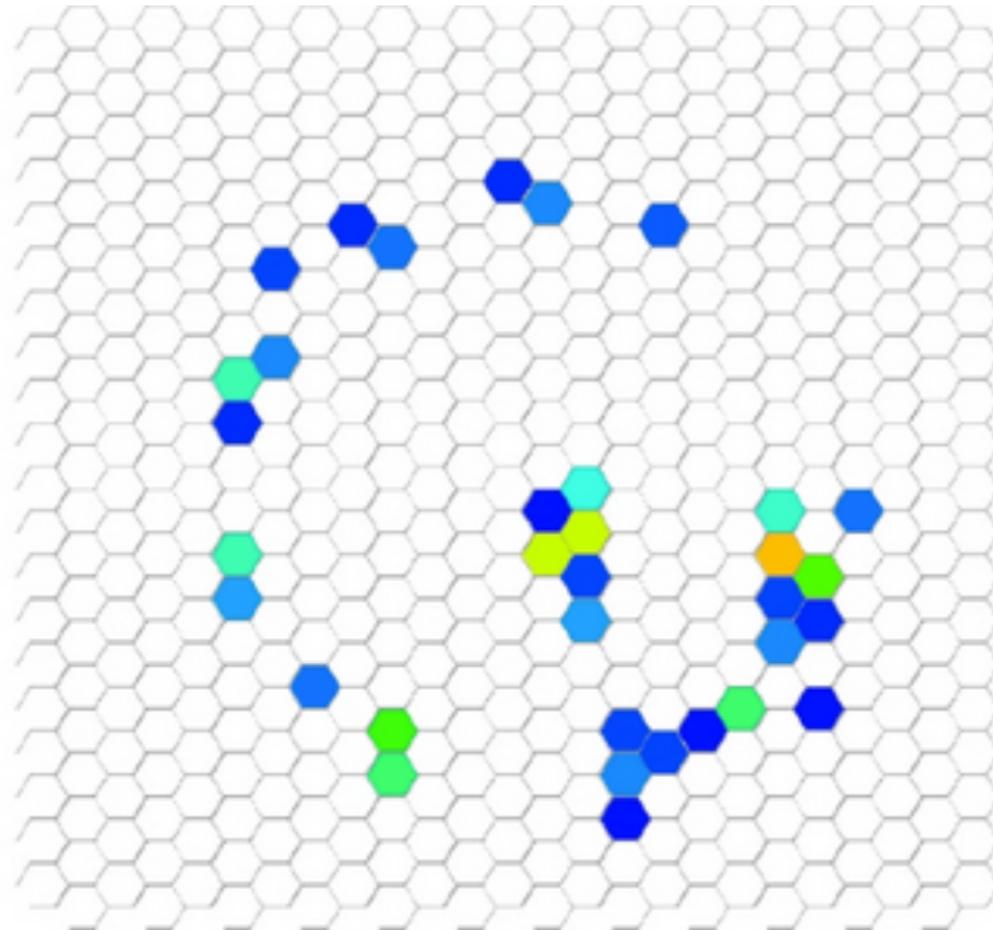
2 Calorimeter:
 $\sigma_E/E = 1.5\%/\sqrt{E}$
 $\sigma_E/E = 12\%/\sqrt{E}$

arXiv:1402.1209v1

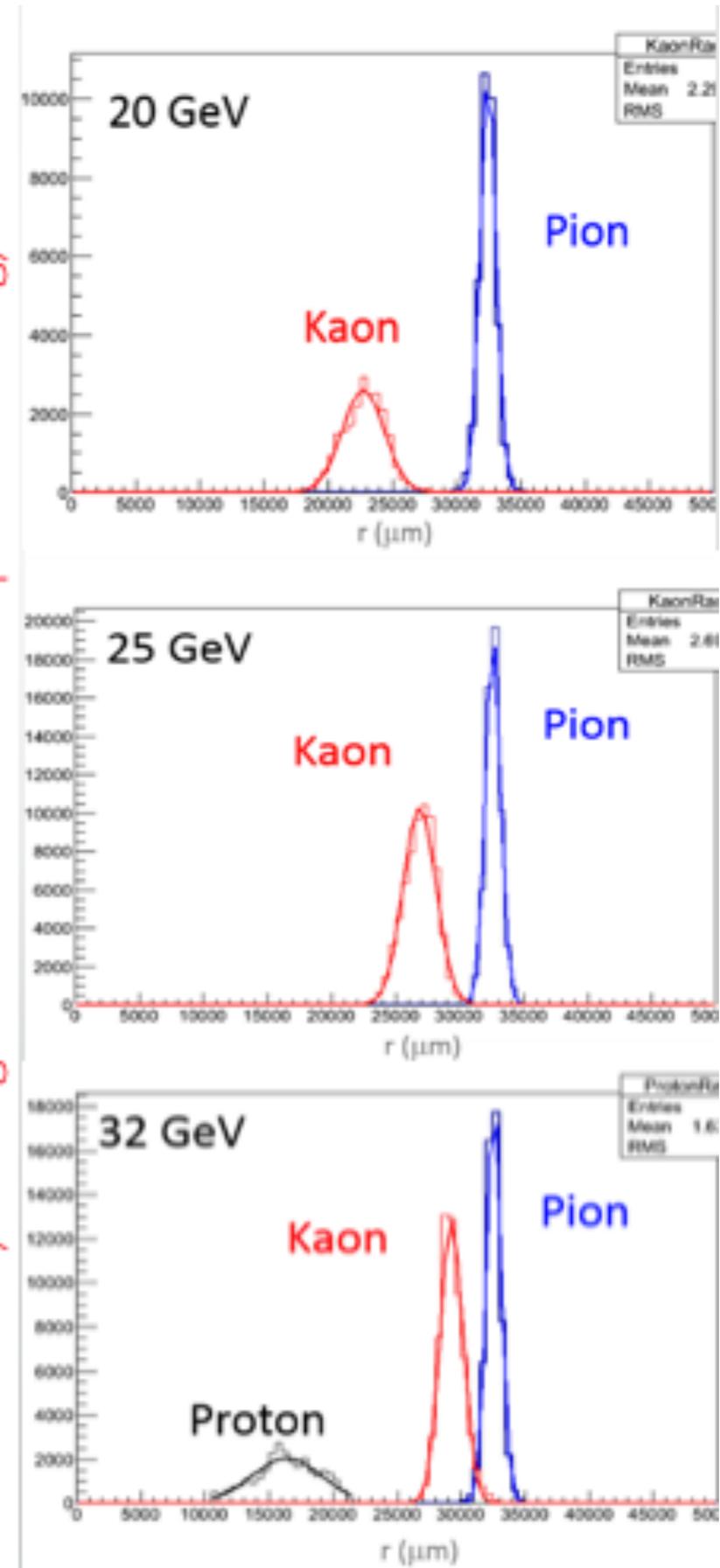
EIC R&D: Gas RICH

EIC R&D project eRD6

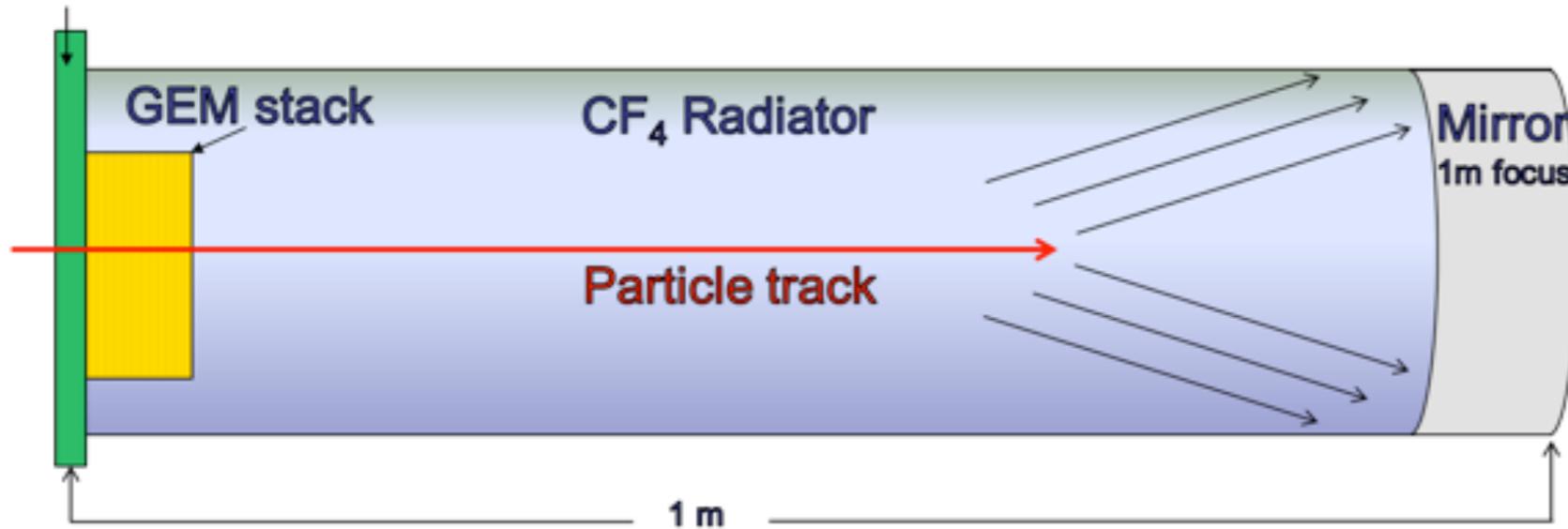
SBU Students:
 Thomas Videbaek
 Stefanie Zajac
 Marie Blatnik
 and others



Easily Distinguished Hadrons to top FNAL Energy

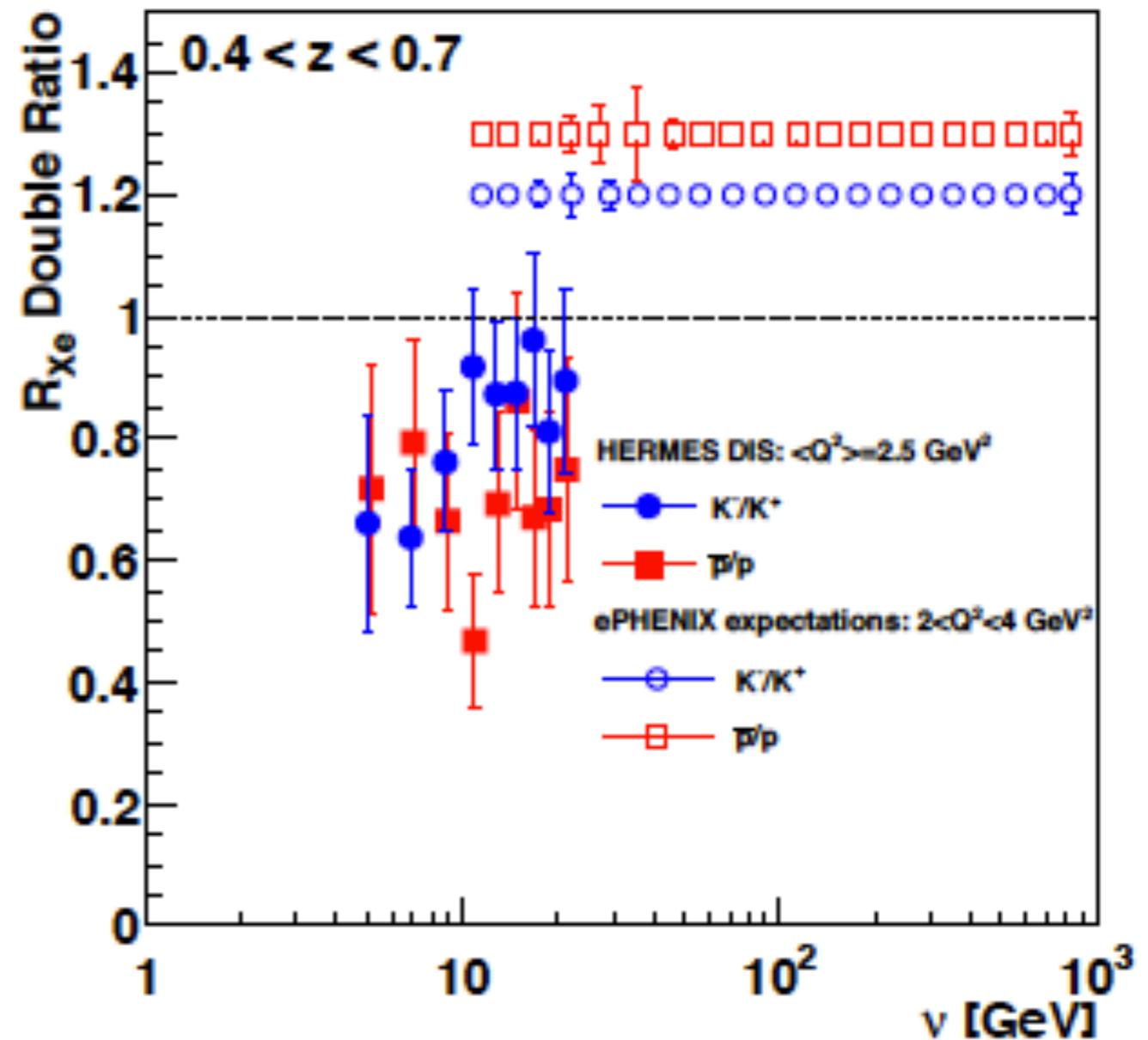
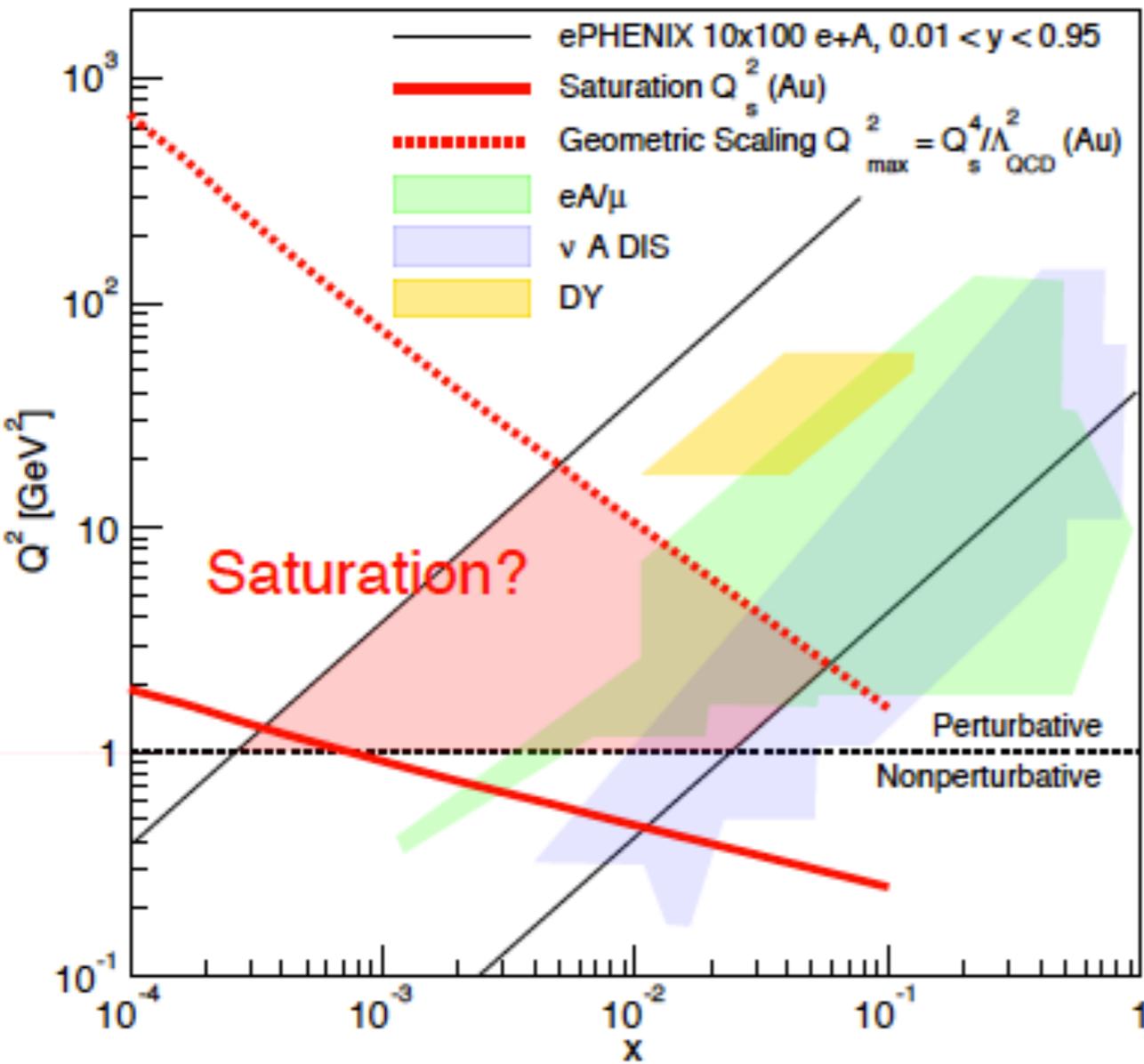
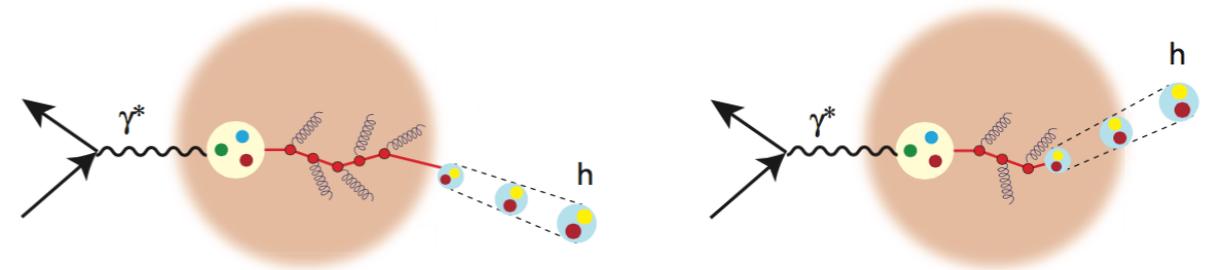


Readout electronics



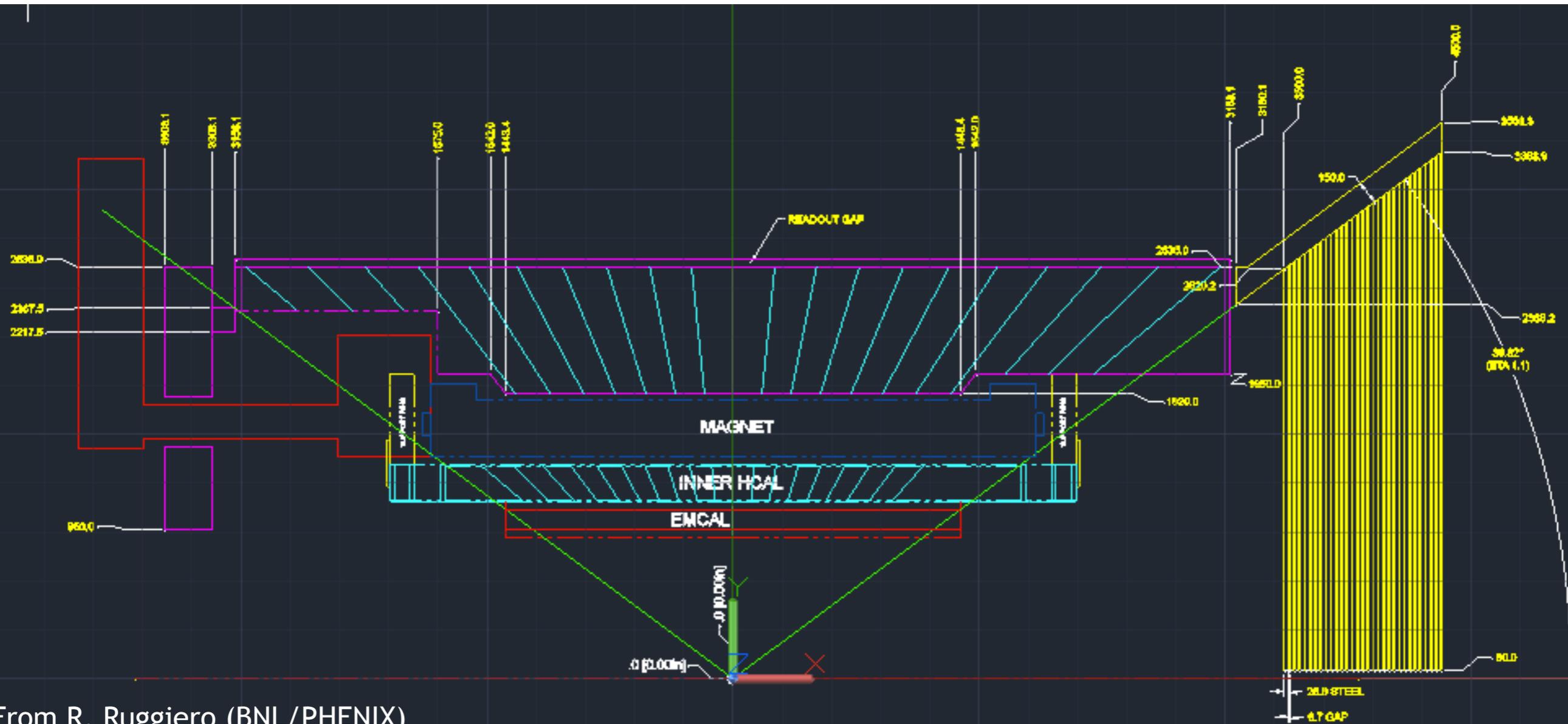
e+A Physics Opportunities

$$Q_s^2(x) \propto \left(\frac{A}{x}\right)^{1/3}$$



arXiv:1402.1209v1

Updated mechanical design for EIC Detector / fsPHENIX

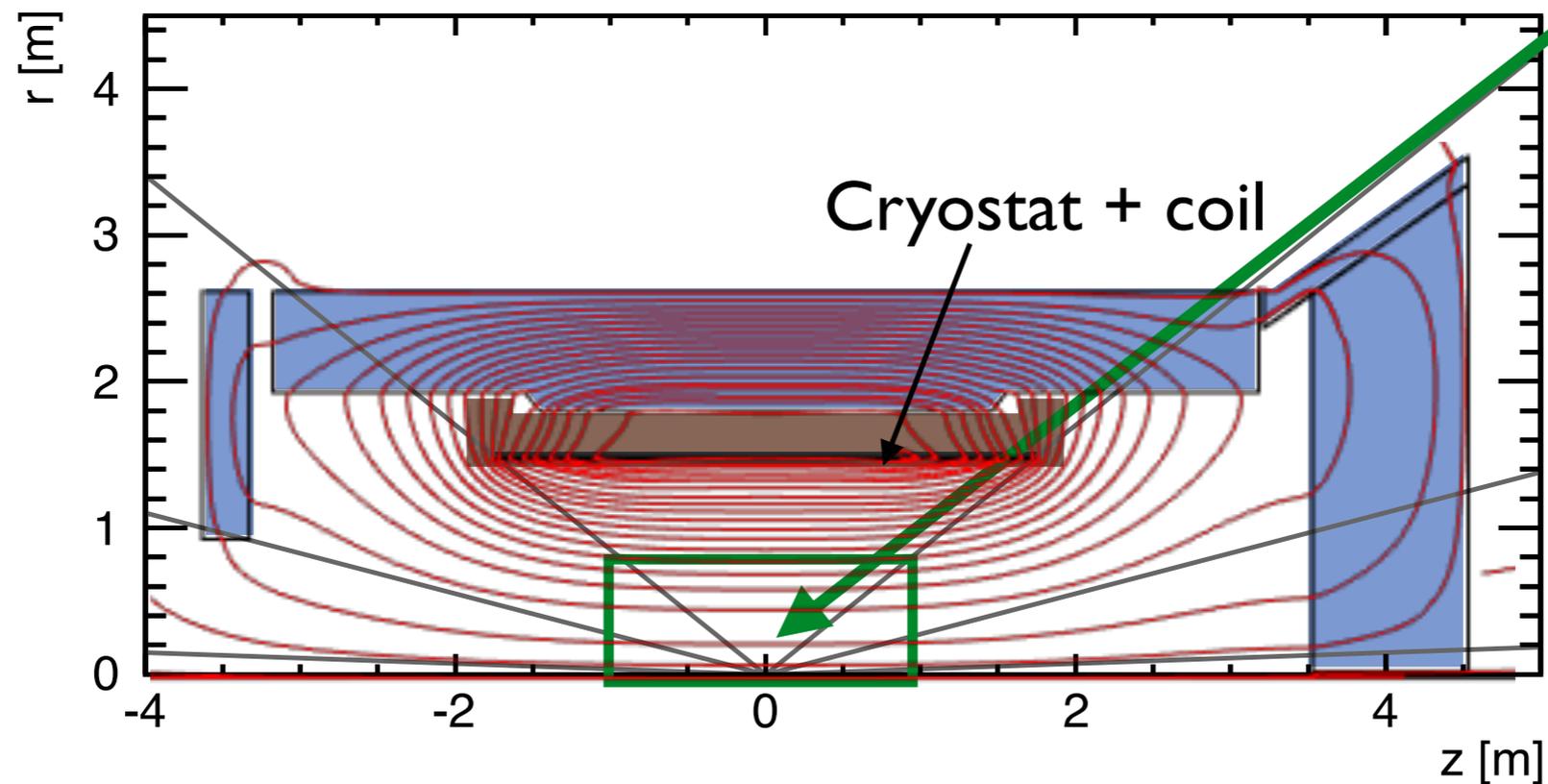


The Central Element: The BaBar Coil



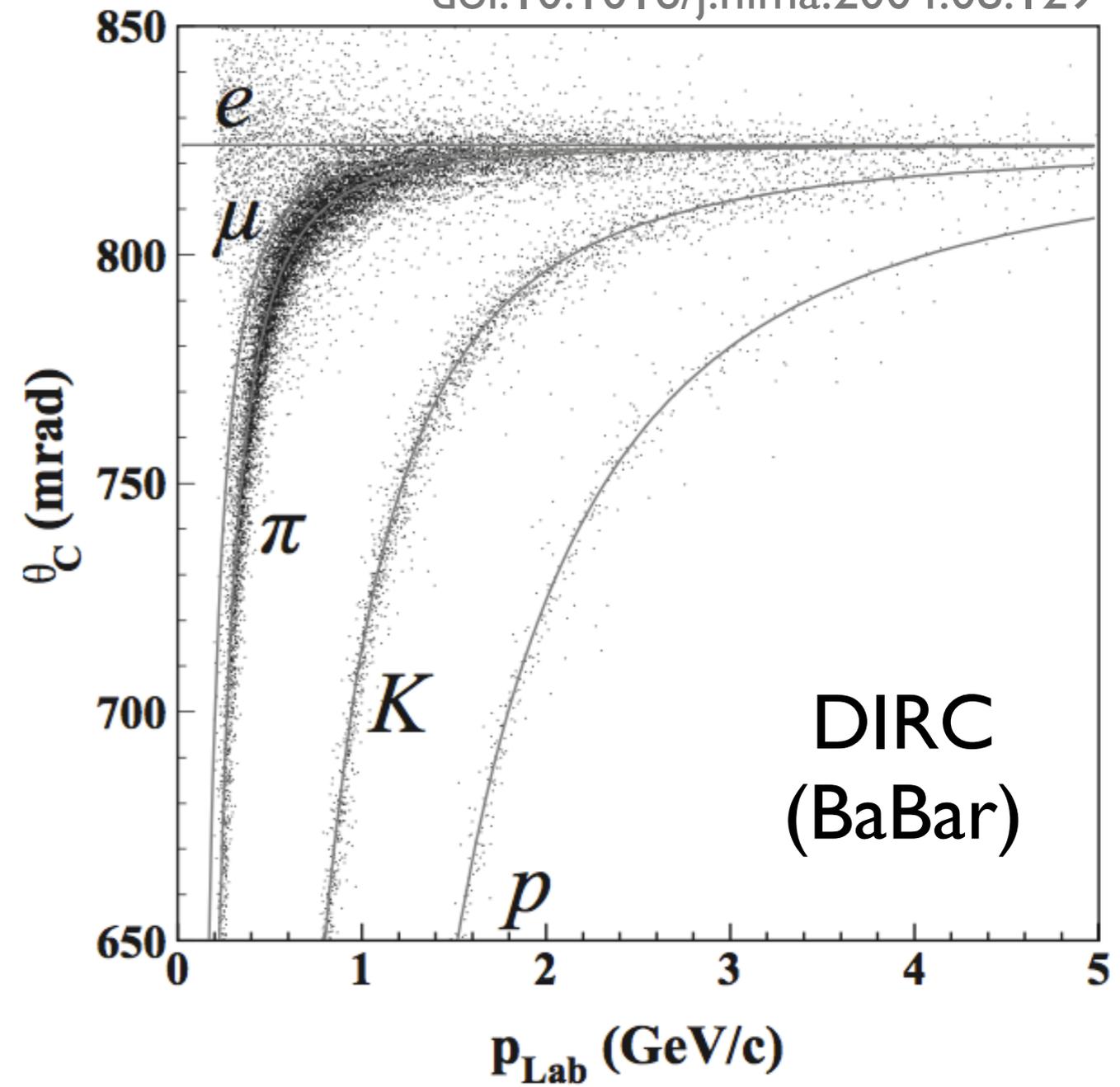
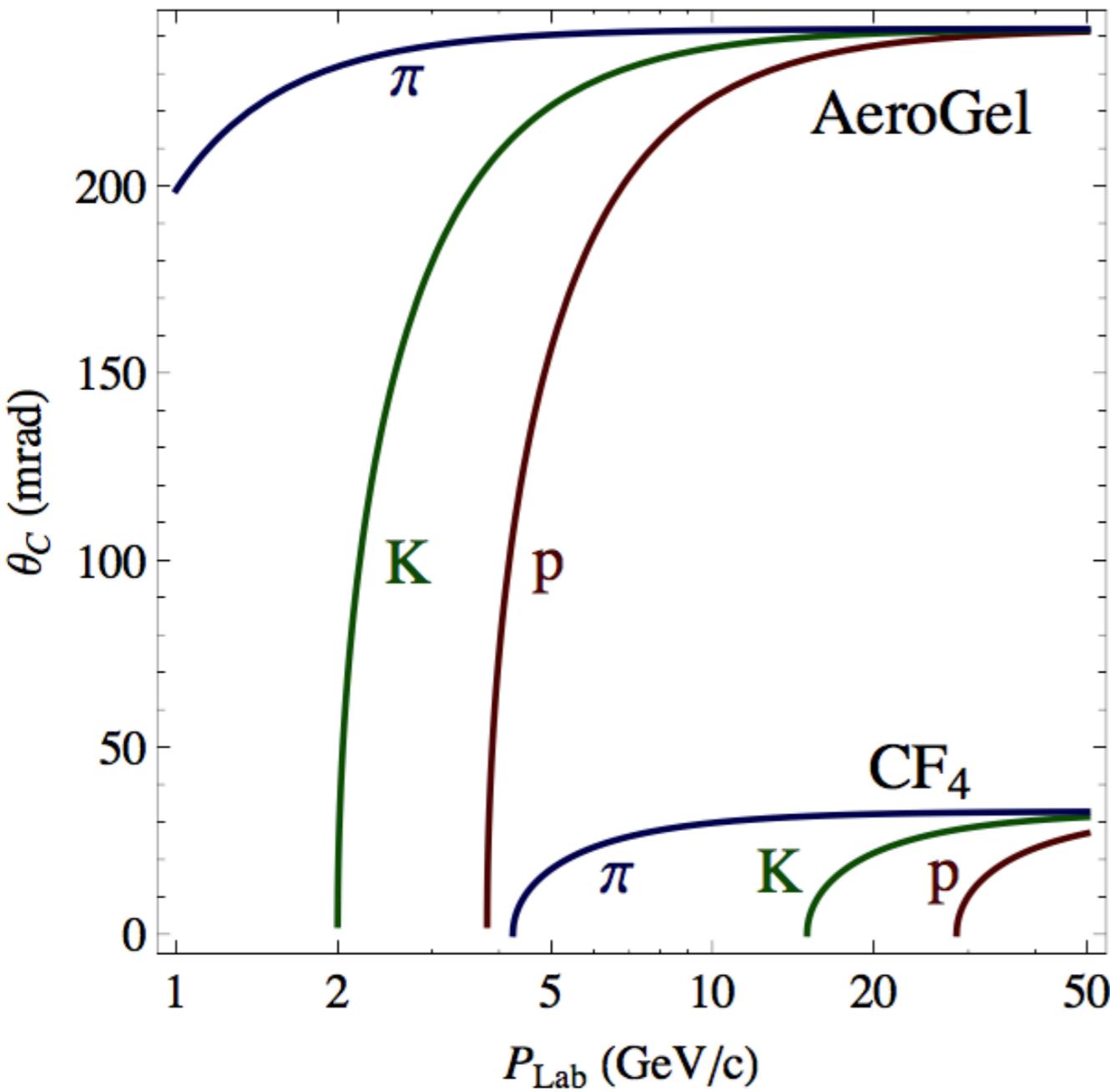
- ✓ Superconducting Solenoid
- ✓ Field: 1.5T
- ✓ Inner radius: 140 cm
- ✓ Outer radius: 173 cm
- ✓ Length: 385 cm

Inhomogeneity < 3%

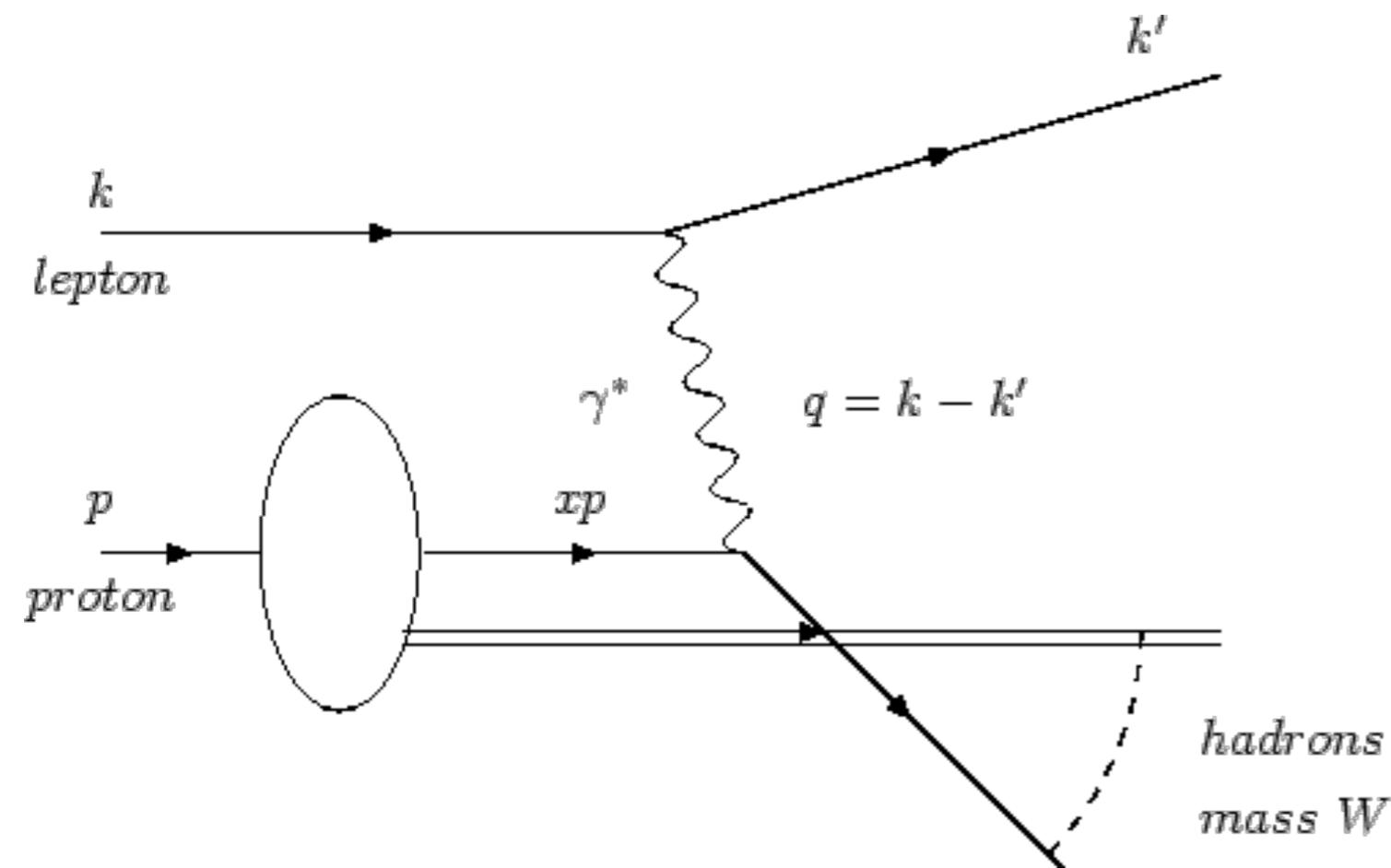


Hadron ID Performance for EIC

doi:10.1016/j.nima.2004.08.129



Deep Inelastic Scattering (DIS)



s = collision energy (squared)

$Q^2 = -q^2 = -(k - k')^2 =$
momentum transfer /
resolution

x = momentum fraction of
struck quark

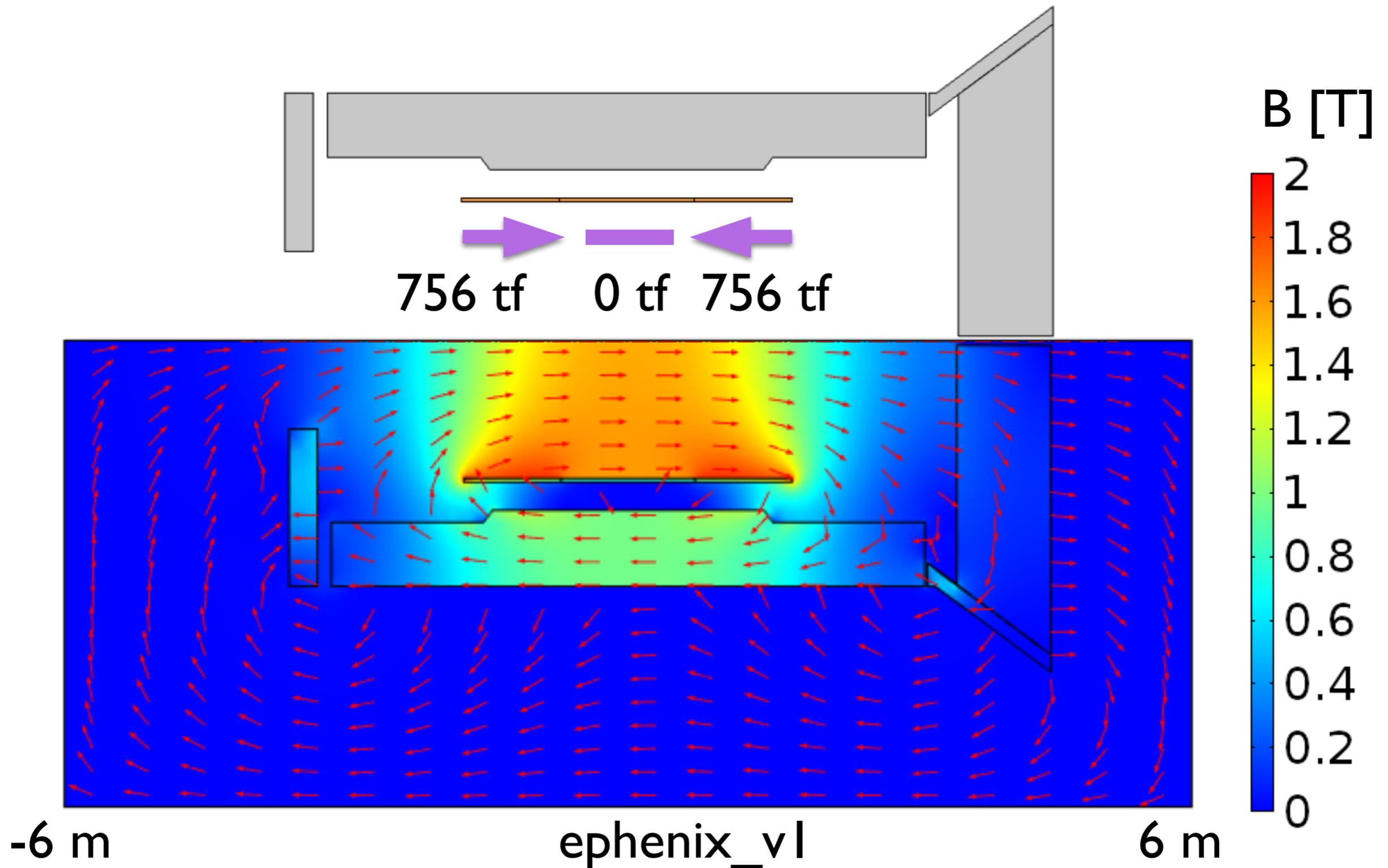
$y = (q \cdot p) / (k \cdot p) =$ inelasticity

Relation: $Q^2 = s x y$

$z = (P_h \cdot P) / (q \cdot P) =$ momentum fraction of the final state hadron
with respect to the virtual photon

$W^2 =$ squared invariant mass of the produced hadronic system

Magnetic field in COMSOL



Magnetic field in COMSOL

